

**The Impact of
Domestic Cats (*Felis catus*) Living Around
Travis Wetland, Christchurch,
New Zealand**

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Batman, a home range and prey retrieval participant, wearing a harness with a small GPS device attached.

Abstract

Cats all over the world hunt wild animals and can contribute to the extinction of threatened species. In New Zealand, around half of all households have at least one cat. When cats live close to a natural area, such as a wetland, they may have impacts on native species. A previous study on the movements and hunting behaviour of domestic (house) cats around the Travis Wetland, Christchurch, New Zealand during 2000-2001 raised concerns about the effects of cats on the local skink population, as skinks were a frequent prey item.

My study is a comparison to the prior study, to determine if impacts have changed alongside changes in human populations in the area post-earthquake. The domestic cat population in the area was estimated by a household survey in March-April 2018. For a 6 month period from March-September 2018, 26 households recorded prey brought home by their 41 cats. During April-July 2018, 14 cats wore Global Positioning System (GPS) devices for 7 days each to track their movements. Skink abundance was measured with pitfall trapping over 20 days in February 2018.

There were more households in the area in 2018 than there were in 2000, but the numbers of cats had decreased. In the 196 ha study area around Travis Wetland, the domestic cat population was estimated at 429 cats, down from the previous 494. Most of the cats were free roaming, but the majority had been desexed and many were mostly seen at home.

A total of 42 prey items were reported from 26 households and 41 cats over 6 months. Of these, 62% were rodents, 26% were exotic birds, and 12% were native birds. There were no native skinks, other mammals, or other vertebrates such as fish and amphibians (invertebrates were not included in this study).

Eight male and six female cats were tracked by GPS. Home range sizes for the 100% minimum convex polygons (MCPs) ranged from 1.34 to 9.68 ha (mean 4.09 ha, median 3.54 ha). There were 9/14 (64%) cats that entered the edge of the wetland. Males had significantly larger home range areas at night and in general compared with females. However, age and distance of the cat's household to the wetland did not have a significant effect on home range size and there was no significant correlation between home range size and prey retrieved.

In 20 days of skink trapping, 11 *Oligosoma polychroma* were caught. The estimated catch rate was not significantly different from an earlier study on skink abundance in Travis Wetland. The apparently low abundance of skinks may have been the result of successful wetland restoration creating less suitable skink habitat, or of other predators other than cats.

In the future, increased education should be provided to the public about ways to increase wildlife in their area. This includes creating lizard friendly habitat in their gardens and increasing management for cats. Generally, only a few cats bring home prey often, and these select cats should be identified in initial surveys and included in further studies. In New Zealand, until management programmes can target all predators in urban areas, domestic cats could stay out at night and inside during the day to help decrease the abundance of rodents at night and reduce the number of birds and lizards caught during the day.

KEYWORDS: Conservation, domestic cat, *Felis catus*, GPS, pitfall trapping, population density, predation, prey, skink, wetland.

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Chapter 1: Introduction

1.1 Cats as Predators

Global biodiversity is affected by various drivers, such as habitat change, overexploitation, pollution, climate change, and a focus of this research; invasive species (Butchart et al., 2010; Nogales et al., 2006; Sakai et al., 2001). An invasive species is defined by a species that has been introduced to a specific location where it is not native, and it causes various degrees of economic, environmental, or ecological degradation (Sakai et al., 2001). Invasive species usually overpopulate areas, compete with native species for food, and may cause the extinction, extirpation, or decline of other species (Baker et al., 2008). When humans reach new locations they often bring their predatory pets and other animals along with them. Wildlife around towns and within must face not only their natural predators, but also introduced ones.

In New Zealand, rabbits (*Oryctolagus cuniculus*), red deer (*Cervus elaphus scoticus*), gorse (*Ulex europaeus*), weasels (*Mustela nivalis*), ferrets (*Mustela putorius furo*), stoats (*Mustela erminea*), possums (*Trichosurus vulpecula*), kiore (Pacific rats, *Rattus exulans*), Norway/brown rats (*Rattus norvegicus*), black rats (*Rattus rattus*), house sparrows (*Passer domesticus*), hedgehogs (*Erinaceus europaeus occidentalis*), and cats (*Felis catus*) are examples of invasive species (King, 2005; Linnæus, 1758). Many New Zealand native birds, reptiles, frogs, and invertebrates had no evolutionary strategies to deal with introduced predators and hunting and subsequently became extinct (Holdaway, 1989). For example, cats and kiore were the cause of the total extinction of the Little Barrier snipe (*Coenocorypha aucklandica barrierensis*) and the local extinction of the North Island saddleback (*Philesturnus carunculatus rufusater*) on Little Barrier Island (Girardet et al., 2001; Veitch, 2001). With introduced predators there is also increased competition for food and habitat with the native species (Holdaway, 1989). Many invasive predators thrive because they eat a wide range of food, and often do not have efficient predators themselves (Sakai et al., 2001). Humans, possums, pigs, birds of prey, and dogs (*Canis familiaris*) may attack or kill cats, and especially kittens, but very rarely. Otherwise, cats in New Zealand roam and hunt without the threat of predation.

The role of mammalian predators currently in New Zealand has been debated. King (1984) had a positive view on the future of wildlife in New Zealand. She concluded that all the extinction events that could have occurred would have happened already and we should accept the mammalian predators as part of New Zealand's fauna. However, Innes et al. (2010) came to a more pessimistic outlook for the future of wildlife, specifically forest birds, if there is not an increase in predator control. The following forest birds may be in trouble if nothing is done: South Island (SI) saddleback (*Philesturnus carunculatus*), kakapo (*Strigops habroptilus*), hihi (*Notiomystis cincta*), North Island (NI) kokako (*Callaeas wilsoni*), blue duck (*Hymenolaimus malacorhynchus*), mohua (*Mōhoua ochrocephala*), kaka (*Nestor meridionalis*), orange fronted parakeet (*Eupsittula canicularis*), NI brown kiwi (*Apteryx mantelli*), great spotted kiwi (*Apteryx haastii*), yellow-crowned parakeet (*Cyanoramphus auriceps*), rifleman (*Acanthisitta chloris*), longtailed cuckoo (*Eudynamys taitensis*), NZ pigeon/kererū (*Hemiphaga novaeseelandiae*), little spotted kiwi (*Apteryx owenii*), NI saddleback (*Philesturnus rufusater*), red-crowned parakeet (*Cyanoramphus novaezealandiae*), brown creeper (*Mohoua novaeseelandiae*), shining cuckoo (*Chrysococcyx lucidas*), and SI tomtit (*Petroica macrocephala macrocephala*) (Hitchmough et al., 2007). Predation by introduced mammals is usually the main cause of decline in vulnerable species (Innes et al., 2010). Many species are now only found on predator-free smaller islands (Girardet et al.,

2001). For example, SI saddleback, kakapo, hihi, little spotted kiwi, and NI saddleback are extinct in the wild on the mainland (Hitchmough et al., 2007; Innes et al., 2010). In the absence of introduced mammals, populations of birds may be limited by habitat area, food supply, disease, and avian predators (Innes et al., 2010). These factors should still be considered in management programmes, but at a smaller scale compared with predator control. The following forest birds are currently not at risk: NI robin (*Petroica longipes*), SI robin (*Petroica australis*), whitehead (*Mohoua albigilla*), NI tomtit (*P. m. toitoi*), morepork (*Ninox novaeseelandiae*), tui (*Prothemadera novaeseelandiae*), bellbird (*Anthornis melanura*), fantail (*Rhipidura fuliginosa*), silvereye/wax-eye (*Zosterops lateralis*), and grey warbler (*Gerygone igata*) (Hitchmough et al., 2007).

Indirect effects on wildlife from predators such as cats are also important to consider. Soil and water can be contaminated by *Toxoplasma gondii* oocysts that are shed by cats in their feces (Howe et al., 2013). *T. gondii* oocysts have been part of the cause of mortality in humans, sea otter (*Enhydra lutris*), dolphin (*Cephalorhynchus hectori*), guinea fowl (Family Numididae), kakariki (*Cyanoramphus* spp.), kererū, North Island brown kiwi (*Apteryx mantelli*), and North Island kaka (*Nestor meridionalis*) (Howe et al., 2013). It was found that there is an association between *T. gondii* infection and abortion in women (Al-Hamdan & Mahdi, 1997). *T. gondii* can also control some rodents by affecting how they behave in the face of danger, where fear is reduced when faced with cats (Tompkins & Veltman, 2015). Cats also carry ringworm and hookworms which can spread to other cats and wildlife (Proulx, 1988) and a protein called Fel d 1 is produced in cat's skin and can induce asthma attacks in some people (Custovic et al., 1998).

Three groups of species vulnerability have been defined for the large New Zealand extinction event that occurred over the last 1000 years (Holdaway, 1989). Group I was 1000-1200 AD and included small flightless birds that declined from hunting by Polynesians and predation by introduced dogs and kiore (Holdaway, 1989). Group II was 1200-1780 AD and involved more resilient species such as moa and the eagle *Harpagornis moorei* that were eventually affected through intensive Polynesian hunting and habitat fragmentation (Holdaway, 1989). Group III was from 1780 to 1986 and affected species vulnerable to European hunting, predation from introduced European mammals, including cats, competition for resources by mammalian herbivores, and habitat destruction in wet forest and wetland habitats (Holdaway, 1989). The species affected included shore plover (*Thinornis novaeseelandiae*), kokako (*Callaeas cinerea*), bush wren (*Xenicus longipes*), saddleback (*Philesturnus carunculatus*), and piopio (*Turnagra capensis*) (Holdaway, 1989).

Without greatly increased predator control even more of the in-trouble birds and other wildlife may become extinct (Innes et al., 2010). However, reducing the population of an invasive species, such as cats, must be carried out with food web interactions in mind (Girardet et al., 2001). Food webs can be extremely complex and only once one part has been removed will hidden interactions come forward (Girardet et al., 2001). One example is the removal of cats from Little Barrier Island during 1976 to 1980 (Girardet et al., 2001; Towns et al., 1997). It was expected that forest bird numbers would increase but instead predation by kiore on Cook's petrels increased and their numbers decreased (Rayner et al., 2007). Only after the removal of kiore, the only other introduced predator present, from the island in 2004 did the petrel numbers and breeding success increase, a clear example of how mesopredator release plays its part in food web dynamics (Rayner et al., 2007).

Origin of the Domestic Cat

The ancestor of domestic cats is the African wildcat (*Felis lybica*) (Harper & White, 2008; Wilkins, 2007). It is thought that the African wildcat was domesticated by ancient Egyptian farmers to keep grain storage areas free from rodents (Wilkins, 2007). Cats were worshipped

in Egypt, Thailand, Japan, and Norway for their beauty and success at keeping rodents at bay, and sailors helped spread cats across the world (Wilkins, 2007). The native cat of the British Isles, *Felis silvestris*, crossbred with the new arrivals (Wilkins, 2007). However, during the Middle Ages the Catholic Church linked them with witchcraft and orders were sent out to burn all cats and cat lovers (Wilkins, 2007). There was a subsequent huge increase in rodent numbers across Europe, and rats carrying fleas infected with bubonic plague spread the Black Death (Wilkins, 2007). Eventually, around the seventeenth century, cats were allowed again and kept as pets, and rat numbers started to drop (Wilkins, 2007). Queen Victoria inherited the throne in 1837 and her love of cats helped to restore their good reputation of ancient times (Wilkins, 2007). In the late 1800s, theories created by Louis Pasteur about microbes created fear for dirty animals (Harper & White, 2008). Cats had a reputation for cleanliness and quickly rose in status as an acceptable pet (Harper & White, 2008). Consequently, globally cats are now kept as pets in high numbers. In the United States there is an estimated 59 - 65 million (Ash & Adams, 2003), in Britain there is an estimated 9 million (Woods et al., 2003), and in Australia there is at least 2.6 million domestic cats (Brickner, 2003).

In New Zealand domestic cats were first introduced in 1769 by Captain James Cook and became established soon after when more arrived with European settlers (King, 2005). The early explorers kept cats on their ships to control the rodents (King, 2005). The distribution of cats increased during the late 1800s when they were released onto farmlands to assist in controlling rabbit populations, and now they are found all throughout New Zealand except for many of the offshore islands (Gillies, 1998; King, 2005). For around 250 years cats have been living alongside native fauna, although they have also caused some declines and extinctions (King, 2005).

Cats can be defined into three different categories, these are domestic or household cats, stray cats, and feral cats (Farnworth et al., 2010). Domestic cats have owners that care for all their needs, stray cats were once domestic but have been cast out or lost, and feral cats were never socialised with humans or were strays that lost their social ability (Farnworth et al., 2010). Feral and stray cats are collectively called free-roaming cats (Levy et al., 2003). Free-roaming cats have been defined as truly feral or semi-feral where the first is fully independent of humans and the latter may be provided some shelter and food occasionally (Baker et al., 2008; Farnworth et al., 2010). Feral cat population abundance is usually dependent on the availability of prey, compared with domestic and stray populations being the result of human actions (Baker et al., 2008). In my study the focus will be on domestic cats.

Physical Attributes of the Cat

Cats bodies are designed to assist them in being successful predators. Their most important sense is vision. Cats have excellent vision in low light because of the presence of their tapetum lucidum, a mirror like coating in their eye, which reflects light onto the back of the retina helping them see in the dark (Wilkins, 2007). Cats have wider peripheral vision than humans and they can detect very small movements of prey (Wilkins, 2007). Their great sense of hearing also increases their skill as a predator as they can hear very quiet sounds (Wilkins, 2007). They can hear up to 65 kilohertz (kHz), whereas humans can only hear up to 20 kHz (Wilkins, 2007). This allows them to hear the slight squeaking of mice from far away. Their nose also helps to detect prey, as there are 200 million odour sensitive cells, compared with human noses which have 5 million (Wilkins, 2007). Cat paws are filled with nerves and they can feel vibrations through their tough pads (Wilkins, 2007). Once they have identified prey through a combination of sight, smell, sound, or feel, retractable claws allow cats to silently stalk and then strike, using their claws to grip their target (Harper & White, 2008; Wilkins, 2007).

Domestic Cats

Past studies have shown that cats kill significant amounts of prey (van Heezik et al., 2010). Domestic cats with regular food sources catch on average significantly less prey than free-roaming cats but can still have an impact (Barratt, 1998; Churcher & Lawton, 1987; Fitzgerald, 1990), although the magnitude of the impact is still uncertain. One argument is that the impact of predation by domestic cats is exaggerated, and because cats are successful pest controllers of animals such as rats and mice, they may provide indirect benefits for native species (Fitzgerald, 1988; Kikillus, Woods, et al., 2017). Others have argued that current predation rates are having a negative impact on native species and that killing of rodents is only a small compensation for the damage cats do to native wildlife (Kikillus, Woods, et al., 2017). Cat breeding results in neglected kittens and increased cat abundance, fighting with other cats causes neighbourhood disturbance, and cats can ruin gardens by digging and spraying (Kikillus, Woods, et al., 2017). Other impacts include competition for important food and space resources, changes in ecological systems, disease transmission, and behaviour changes of prey via induction of stress (Kikillus, Chambers, et al., 2017; Kikillus, Woods, et al., 2017).

New Zealand has one of the highest levels of cat ownership in the world, with half of all households owning at least one cat (Kikillus, Chambers, et al., 2017; Morgan, 2002; van Heezik et al., 2010). This high number has resulted in studies of the effect that predation by domestic cats has on wildlife. The first study on urban domestic cat impacts near conservation areas in New Zealand was carried out in Auckland and concluded that domestic cats do pose a threat to vulnerable wildlife (Gillies, 1998). Households with cats that are near reserves or natural spaces may have a large impact on the populations of wildlife living there (Gillies, 1998).

The first study on domestic cat impacts in Christchurch was carried out by Shelley Morgan in 2000/2001 and was based around the Travis Wetland reserve (Morgan, 2002; Morgan et al., 2009). She showed that the majority of prey brought home were rodents, but there were also large amounts of native skinks caught (Morgan, 2002). She found that only 21 out of 981 (2%) prey items brought home over a year by 88 cats were native birds and 172 were native skinks (18%). The prey composition was 38% rodents, 22% invertebrates, 18% exotic birds, 18% skinks, 2% native birds, and 2% other prey. Out of the 199 birds total there were 21 native birds. The total bird composition was 8% silvereyes, 2% fantails, 1% kingfisher (*Halcyon sancta vagans*), and 1% welcome swallow (*Hirundo neoxena*) for native birds. The exotic birds were caught more often with 37% house sparrows, 13% blackbirds (*Turdus merula*), 9% goldfinches (*Carduelis carduelis*), 7% starlings (*Sturnus vulgaris*), 6% song thrush (*Turdus philomelos*), 5% ducks (various species), and 5% greenfinch (*Carduelis chloris*). The other 6% of birds consisted of one magpie, one pigeon (presumably the introduced rock pigeon, *Columba livia*), and unknown birds.

A similar study was carried out in Dunedin by van Heezik et al. (2010). They found that cats less than a year old brought home more prey than older cats (van Heezik et al., 2010). Prey retrieval data from 144 cats over a year showed that composition was 34% rodents, 20% exotic birds, 20% invertebrates, 16% native birds, and 8% skinks. There were 1887 prey items in total. The 306 native birds consisted of silvereyes, fantails, tui, bellbirds, and kererū. The 374 exotic birds consisted of blackbirds, house sparrows, song thrushes, starlings, goldfinch, greenfinch, dunnoek (*Prunella modularis*), chaffinch (*Fringilla coelebs*), redpoll (*Carduelis flammea*), yellowhammer (*Emberiza citrinella*), and mallard (*Anas platyrhynchos*). Compared with the sample of cats from the Travis Wetland area, the Dunedin cats were having a larger effect on native birds, and on birds in general. Of the cats in the van Heezik et al. (2010) study, 17% were bringing home skinks.

The skink of most concern in these studies was the grass skink, *Oligosoma polychroma* (Bell, 2014; Freeman & Freeman, 1996; Morgan, 2002; van Heezik et al., 2010). Cats are

effective predators of lizards and may reduce local population abundance, or even drive them locally extinct (Case & Bolger, 1991; Norbury, 2001). Predation by cats has been found to be inversely density-dependent as predation increased when skink densities were low (Norbury, 2001). Predation by cats, and ferrets, did not have as big an impact on skink mortality when they were present in higher densities (Norbury, 2001).

Van Heezik et al. (2010) raised concerns about the prey retrieval survey method where the number of prey items brought home by cats is only a proportion of the total deaths, especially for invertebrates. The results from studies on domestic cats may greatly underestimate the amount of wildlife caught each year. Cats may catch around three times more prey than they bring back home (van Heezik et al., 2010). A study in south eastern USA using “Kittycam” video cameras on 55 free-roaming domestic cats shared that reptiles, mammals, and invertebrates were the main prey caught and 44% of the cats hunted this wildlife (Loyd et al., 2013). Only 23% of prey items were brought back to households, 49% were left at the site and 28% were eaten (Loyd et al., 2013).

Free-roaming Cats

To get a clearer picture of the effects that cats have on wildlife, both domestic and free-roaming cats need to be considered. Studies on free-roaming cats are often carried out with scat analysis which involves identifying prey items from undigested bones and teeth (Malo et al., 2004). Biomass is often used in prey analysis, usually estimated from past studies (Malo et al., 2004). The mean weight of prey species is estimated from numerous measurements of individual weights (Malo et al., 2004). Larger prey items (rabbits or larger) and smaller prey items (insects, lizards, and amphibians) may be underrepresented in prey retrieval studies compared with the scat analysis carried out for free-roaming cats (Loyd et al., 2013).

Free-roaming cats are generalist predators because they feed on a wide range of available prey (Bonnaud et al., 2007) but they show some facultative specialisation of rabbits and rodents (Malo et al., 2004). Predators are generalists when abundance of preferred prey is low and they are specialists when abundance is high (Malo et al., 2004). A facultative specialist is opportunistic as they will change their main prey if another more profitable prey is abundant (Bonnaud et al., 2010). Small mammals such as rats are often cats preferred prey and can form a large part of their diet (Bonnaud et al., 2007). However, when rodents and rabbits are present together, rabbits are the main prey of cats (Bonnaud et al., 2010; Malo et al., 2004). Malo et al. (2004) found that cats consumed significantly fewer rodents when rabbits were present and prey diversity was lower in general. The diet of free-roaming cat's changes in relation to prey availability and hence changes with season changes (Bonnaud et al., 2007). These studies showing rabbits as the preferred prey of free-roaming cats gives insight on the needs of cats. Rabbits have high energetic profitability as only two to three adult rabbits or four juveniles are enough to fill a cat's energetic needs compared with around 30 smaller rodents (Malo et al., 2004). Domestic cats also catch rabbits (Flux, 2007; Malo et al., 2004) but rabbits are present in higher numbers in fields compared with gardens and urban areas (Flux, 2007). Domestic cats have regular food sources so do not require prey for energy needs, and thus catch significantly less prey than free-roaming cats (Barratt, 1998; Churcher & Lawton, 1987; Fitzgerald, 1990). In general, cats can be labelled as opportunistic predators (Fitzgerald, 1988; Lepczyk et al., 2003; Liberg, 1984; Loyd et al., 2013).

Stray and domestic cats living near wildlife reserves in urban areas may pose a threat to the wildlife within. Even though cats prefer preying on rabbits and rodents, in New Zealand there are native birds and skinks that cats will hunt. Many species are vulnerable and are now only found on predator-free offshore islands (Gillies, 1998; King, 2005). So that those at-risk species do not become locally extinct within urban areas, predators such as cats need to be managed to reduce any negative impacts.

1.2 Cat Management Options

Number of Cats

Before management options can be considered for cats, the number of cats needs to be estimated. In 2011 it was estimated that 48% of New Zealand households had one or more cats, with those households having an average of 1.8 cat per household (NZCAC, 2011). There was a total estimate of 1.419 million domestic cats (NZCAC, 2011). In the most recent New Zealand companion animal population breakdown in 2015, cats were estimated to be in 44% of households, with an average number of 1.5 per household (NZCAC, 2016). The total estimate of cats was 1.134 million, a decrease of 300,000 domestic cats (NZCAC, 2016). The same survey methods (online New Zealand Companion Animal Survey among a representative sample of adults) were carried out for the NZCAC information for both years so the change in numbers reflects the slight drop in the proportion of households with cats. The New Zealand Veterinary Association (NZVA) has estimated stray cat numbers to be around 196,000. Estimates of feral cat numbers have a large range of uncertainty of between 2.4 and 14 million. The management of cats will vary depending on whether they are domestic, stray, or feral.

Management of Domestic Cats

The management requirements of domestic cats will depend on their impacts on wildlife. Domestic cats already have owners, are able to be neutered, and eradication is unthinkable. Metsers et al. (2010) and van Heezik et al. (2010) reviewed mitigation methods for domestic cats. Van Heezik et al. (2010) suggested that keeping cats inside at night is an approach that will only reduce catches of rodents in New Zealand, as that is when those small mammals are the most active. Keeping cats indoors both day and night (cat confinement) is one method to solve the problem of negative impacts on wildlife (Metsers et al., 2010). Owners can have the benefits of owning a cat while protecting the wildlife around them (Metsers et al., 2010). An additional benefit of confinement is protection to the cat, as they will not be at risk to traffic accidents and the like (Metsers et al., 2010). However, not many owners keep their cats indoors. A study in Wellington, New Zealand showed only 8% of owners kept their cat indoors or indoors with an outdoor cat run or enclosure (Kikillus, Woods, et al., 2017). In comparison 84% of the cats could go outside (Kikillus, Woods, et al., 2017). Keeping cats indoors confines them from the outdoor environment which can lead a cat to experience boredom and stress (Rochlitz, 2005). They are also less active, which can lead to obesity (Rochlitz, 2005). Being indoors is problematic when natural behaviours such as scratching and spraying urine are carried out (Rochlitz, 2005).

Another method is to prohibit cats from suburbs that are close to areas of high conservation value with a cat-exclusion buffer zone (Metsers et al., 2010). Gillies (1998) also suggested that households near habitat with native species presence should not own cats. The cat buffer zones and indoor only rules may not work, as it would be hard to convince people in a set area not to own cats, or keep them indoors all the time, as they often do not see their cat as a problem (van Heezik et al., 2010). Owners are often unaware that small predation effects add up over time with multiple cats, which can create a larger problem. Management tools include targeting the most active hunters and reducing cat density, which would require awareness of cat owners of the impact their cat has on the wildlife (van Heezik et al., 2010). However, even if the number of cats per household were reduced, cats from further away may move into these newly open areas to expand their home ranges (van Heezik et al., 2010). Metsers et al. (2010) had a more positive outlook of cat buffer zones than van Heezik et al. (2010). They suggested that the size of an exclusion zone should vary with the habitat,

residential development amount, variability between each cat, and the importance of native species needing protection. These would need to be measured with each scenario.

Cats have a variable range depending on specific habitats. In Japan, urban free-roaming cats range over less than 1 ha whereas in Australia free-roaming cats range up to 2000 ha (Kikillus, Chambers, et al., 2017). Within a region, male, larger, and rural cats near these natural areas tended to have larger home ranges (Kikillus, Chambers, et al., 2017).

Cat ownership currently has fewer rules compared with rules placed around dogs. Dogs must be registered and must be on a lead in certain places. Because there are widely differing views on cats, getting people to agree to management tools such as cat registration or ownership restrictions would be very difficult (Metsers et al., 2010). Informing people that they cannot own a cat in a certain area may be seen as a breach to their freedom and they may care more about their cats than impacts on wildlife such as birds and skinks (Metsers et al., 2010). But the idea does work as already there are predator and cat free subdivisions in New Zealand set up since the 1990s (Morgan, 2002). These areas include subdivisions in Kapiti Coast, Wellington, and Opito Bay, Coromandel (Morgan, 2002). There was a council notice aimed at the Whangaroa-Waipara-Kerikeri areas to discourage households from keeping cats to protect kiwi living around there (Pierce et al., 2006). Cats have been known to kill kiwi chicks and subadults (Pierce et al., 2006). However, even with buffer zones or cat confinement, free-roaming cats may still enter the at-risk natural areas (Metsers et al., 2010). To reduce this problem, in the Kapiti subdivision there is trapping of pests, including cats (<https://www.newshub.co.nz/home/new-zealand/2016/07/cat-ban-at-new-kapiti-subdivision.html>, November 2018).

Where cat confinement or exclusion is not an option, other ways to manage a cat include cat confinement but with access to the property only (restricted by cat proof fences), or the addition of hunting deterrents on their collars. The BirdsBeSafe® collars and the CatBib™ can reduce the number of birds caught (Calver et al., 2007; Gillies & Cutler, 2001; Willson et al., 2015). It has been found that cats without Birdsbesafe® collars on kill 19 times more birds in spring and kill 3.4 times more birds in autumn (Willson et al., 2015). Cats wearing the CatBib™ had a 67% reduction in birds and 44% reduction in mammals caught (Calver et al., 2007). There was a 24% non-significant reduction in reptiles and amphibians caught (Calver et al., 2007). There is also the The Liberator® which sends out audio-visual signals when the cat is about to pounce, and bells which may alert prey to the cats presence (Gillies & Cutler, 2001; Gordon et al., 2010). However, there was not significantly fewer birds, rodents, or lizards brought home when a cat was wearing The Liberator® compared without (Gillies & Cutler, 2001). When wearing a bell, cat predation of birds was reduced 50% and rodents by 61% (Gordon et al., 2010). There was no significant difference in lizard predation (Gordon et al., 2010). In New Zealand, deterrent devices that decrease predation on birds or lizards, but not mammals, are ideal. There is no information on lizards for the BirdsBeSafe® collars, but those and the CatBib™ seem to be the most useful for use in New Zealand.

Management of Free-roaming Cats

There are four options for free-roaming cats; eradication, adoption, sanctuaries, and trap-neuter-return (TNR) (Levy & Crawford, 2004; Levy et al., 2003).

Eradication of free-roaming cats can be carried out with trapping in cages or leg holds, spotlight shooting, poisoning, hunting with dogs, and spreading feline disease (Short et al., 1997). Short et al. (1997) used sodium monofluoroacetate (1080) poison laced laboratory mice (*Mus musculus*) to reduce free-roaming cat numbers in Western Australia. There was a 74% reduction in cat counts and they found that effectiveness was maximised when prey abundance was low. Shooting and trapping can be labour and time intensive and can only be

carried out in smaller areas whereas poisoning can be carried out over large areas and is cost-effective (Short et al., 1997).

However, there is a “no-kill” movement which challenges the welfare of eradication of healthy animals (Levy & Crawford, 2004). Adoption of free-roaming cats is often not successful as the cats are not socialised (Levy & Crawford, 2004). Cat sanctuaries can take in unadoptable cats and are a humane way of managing free-roaming cats, but they rarely have room for new cats (Levy & Crawford, 2004). TNR is a humane method to reduce the number of new cats as free-roaming cats are caught, sterilised, and then returned to their colonies (Levy & Crawford, 2004). Levy et al. (2003) had success with adoption and TNR on a university campus in Florida. Over 11 years the population of cats had decreased by 66%. Around half of the cats were adopted and around 10% were euthanatized when vet care would be unsuccessful. The rest either disappeared or were neutered and then returned. A more intensive version of TNR is trap-test-vaccinate-alter-return (TTVAR) where cats are also tested for feline leukemia and feline immunodeficiency virus, and vaccinated against rabies, as well as neutering them (Ash & Adams, 2003). TTVAR includes the daily feeding and monitoring of cats near the capture site (Ash & Adams, 2003). There is a clash between the cat-rescue movement and wildlife managers where the latter disprove of methods such as TNR and TTVAR where cats are returned to the wild where they may be negatively impacting native wildlife (Ash & Adams, 2003). Surveys given to the general public showed low tolerance for the eradication of cats, even those living in wildlife areas where there is a large threat to prey species (Ash & Adams, 2003).

Other Solutions

Predation may not always be the largest factor in decline of wildlife in urban areas. Focusing on housing density, road design, and reducing habitat fragmentation may provide benefits to birds and other wildlife (Calver et al., 2007). Skink presence has been associated with not only low cat densities, but also low plant species diversity, increased cover, and long grasses (van Heezik & Ludwig, 2012).

1.3 Study Rationale

My aim was to understand the effects of cats on their prey species, looking at skinks in particular. Long term, the goal is to conserve species in urban and wetland areas without the removal of cats.

Morgan’s (2002) study was carried out pre-earthquake, and since the 2011 earthquake large amounts of the area surrounding the Travis Wetland has become part of the ‘red zone’ of Christchurch. The Government defines the red zone for Christchurch flat land as “remediating the land and repairing or rebuilding properties would be uncertain, disruptive, lengthy and uneconomically viable in the short to medium term” (MacDonald & Carlton, 2016). From the Government Statistics Census, in 2006 there were about 2800 people living in the Burwood area. In 2013 however, there were only about 1000. Morgan (2002) in 2000 contacted 204 out of a total of 617 households in the chosen research area around the Travis Wetland. I thought the earthquake and the newly created ‘red zone’ would lead to fewer houses near Travis Wetland and I wanted to see if the impact of cats on wildlife and the density of cats had changed since. Surprisingly, I estimated approximately 715 houses in the same study area (some houses are still under development). There were approximately 98 new households and domestic cat numbers may have changed. With the change of conditions, it was important to estimate if the skink population was stable, or at risk. Freeman and Freeman (1996) suggested that the Travis Wetland has the potential to support other lizard

species that are found in other urban areas in the country and which may thrive with proper management.

Around 1600 years ago, the Travis Wetland in Christchurch formed part of a huge estuary, similar to the Avon-Heathcote estuary of today. In the last 150 years around 90% of wetland areas in New Zealand were lost to draining for farming. The Travis Wetland were no exception as they were drained and used as a dairy farm. However, in 1996 the Travis Swamp dairy farm was purchased by the Christchurch City Council (CCC) and converted into a Nature Heritage Park. Since then the wetland has gradually been restored by generous donations and years of planting and maintenance. Now the Travis Wetland is the largest freshwater wetland left in Canterbury. It is a 119 ha area consisting of less than 20% water with the rest being boggy soil with grasslands and willow tree areas (CCC). Of the 55 species of birds in the area, 35 are natives (CCC). The Travis Wetland is an important conservation location. There are over 700 pukeko (*Porphyrio porphyrio*) which is roughly half of the total Christchurch pukeko population (CCC). Cats, rats, stoats, harrier hawks (*Circus approximans*), dogs and hedgehogs are some of the predators that prey on the birds, lizards, and their eggs, and approximately 800 insect species (CCC). Additionally, birds and mice prey on the invertebrates. Dogs are banned from the wetland, and cats are the only other predator that people have some control over. Post 1996, the Council created a water moat between houses and the wetland to discourage domestic pets from entering (Morgan, 2002). It was found that cats still entered the wetland by jumping, or swimming, across the moats (Morgan, 2002). Therefore, cat management should be directed to the community.

Increasing biodiversity of lizards and other wildlife in the wetland area is a long-term goal, but was not an explicit part of my study. The 2050 Predator Free New Zealand Initiative created in 2016 does not consider predatory domestic animals, so research on cats (plus other animals such as dogs and hedgehogs) is important to understanding their impacts on other wildlife (Kikillus, Chambers, et al., 2017). The community can use this information to carry out informed lifestyle decisions and within that the local Government can make informed decisions regarding animal control.

1.4 Research Objectives

I carried out a prey retrieval and range study to compare with Morgan's (2002) results. I also carried out a comparison of prey brought home by domestic cats in New Zealand and internationally. I estimated skink abundance using pitfall traps.

There are four chapters each devoted to specific objectives;

- To estimate the population of domestic cats in the area for comparison with Morgan's (2002) study and to provide the characteristics of cats in the area to use for further analysis within the following two chapters
- To compare cat movement with Morgan's (2002) study
- To compare cat prey retrieval with Morgan's (2002) study and global results
- To estimate skink abundance at the Travis Wetland

With the increase in household number around the Travis Wetland, I hypothesised that there may be fewer domestic cats overall if fewer people own them around a wildlife area, or there may be more with more households in the area bringing their cats with them when they moved in. If there were fewer domestic cats, more free-roaming cats may move into the area or vice versa. For the prey retrieval study, I asked how many of each prey item are brought

home over a set study period of 6 months. Cat diet varies with prey availability so if there were fewer prey available in the area there may be lower prey per cat per year compared with results from Morgan (2002). If there were fewer domestic cats in the area, there may be relatively fewer prey brought home over the same time-period (assuming free-roaming cat numbers stay the same), even if prey per cat increases. If there was an increased number of domestic cats in the area, relatively more prey may be brought home.

For the home range study, I asked how many domestic cats entered the Travis Wetland and how far did they range. If there were fewer cats in the area, more spaces and territories will have opened so more domestic cats will travel towards the Travis Wetland because of reduced competition. An alternative hypothesis is that if there were more cats than before, the range of domestic cats might be smaller due to increased competition.

I had three hypotheses on skink abundance. (1) Skinks are more abundant towards the center of the wetland, away from zones where they would be at risk from predation. (2) Skink abundance will have decreased from previous estimates because of high cat predation. (3) Alternatively, skink abundance will have increased because volunteers are currently removing invasive weeds which include the grey willow, *Salix cinerea* (CCC). This may have benefits for skinks as they will have more areas of suitable habitat available.

Chapter 2: Cat Abundance and Characteristics around Travis Wetland

2.1 Introduction

Any potential impact that domestic cats have on wildlife is usually the responsibility of the owner (Coleman et al., 1997). Owners are the ones who control their cat's movements by letting them in or out of the house. It is not required that cats are registered in New Zealand, and there is no requirement on owners for desexing and microchipping their cat. Desexing is important as it helps to control the stray and feral cat populations. Cats have a close association with humans and are therefore found in higher concentrations in urban areas compared with more rural or wild areas (Coleman et al., 1997).

There have been various studies focusing on domestic cats in the past, some focusing on personality, and others focusing on information similar to that of my study. The most accurate way to gather data about domestic cats is to survey the households in the study area. However, this method is subject to certain data errors. Information may not follow a standardised format, with each individual writing slightly different answers for what should have been the same piece of information.

As of September 2017, the total household estimate for New Zealand was 1,729,300 (Statistics New Zealand). Using the estimate of 48% of households having cats with an average of 1.8 cats per cat-owning household (see Chapter 1.3), currently there may be around 1.5 million domestic cats in New Zealand. Cities act as sinks for many wildlife, including native birds (van Heezik et al., 2010). Cats are killing native birds in cities faster than they can breed, and populations are only replenished from source populations further out from the city (van Heezik et al., 2010). Working out estimates of cat abundance in at risk areas, such as near nature reserves, is important to see what sort of overall impact the cats may be having. Estimations on abundance and density often underestimate total cats in the area, as free-roaming cats were not included (Kikillus, Chambers, et al., 2017).

This chapter estimated how many domestic cats are living adjacent to Travis Wetland and collated information on their characteristics. The main method to obtain information was a door knock survey in the 196 ha study area (Morgan, 2002). Surveying cat owners about the number and characteristics of their cat was an important first step to recruitment into the GPS and prey retrieval studies. Information given by households about their cats was compared in later chapters focusing on home range (Chapter 3) and prey retrieval (Chapter 4). As part of the survey, owners recorded how far they have seen their cat from their house and how often their cat brings home prey (reported hunting behaviour), but the later chapters go more in depth on these topics using a smaller subset of cats.

2.2 Methods

In my study, similar methods of Morgan (2002) were carried out. Every third household in the 196 ha area around the Travis Wetland was door knocked (Figure 2.1). For the first round of handing out forms, door knocking was carried out between 2 - 6 pm. Many people were not home, and so a second round of door knocking was carried out between 7 - 8.30 pm. To contact the remaining households, forms in envelopes were put in letterboxes. After three attempts at contact, any household who still did not respond was labeled as "No response". Households were asked how many cats they have, to enable an estimation of cat density in the area. If there was at least one cat in the household, they were asked to fill in a one-page

survey similar to the one Morgan (2002) used (see Appendix). This requested information about the cat such as sex, colour, eating habits, and movement restrictions.

An estimate of the total number of houses in the area was obtained from Google Maps (2018). The mean number of cats per household was multiplied by the total number of houses to obtain the estimated number of domestic cats living in the study area. Mann-Whitney U tests (U) were used to compare cat sex and breed with reported hunting behaviour and range the cat had been seen by the owner. Spearman's rank correlation (r_s) was used to compare cat age with reported hunting behaviour and range, and to compare the ranks of reported hunting behaviour and range the cat had been seen by the owner.

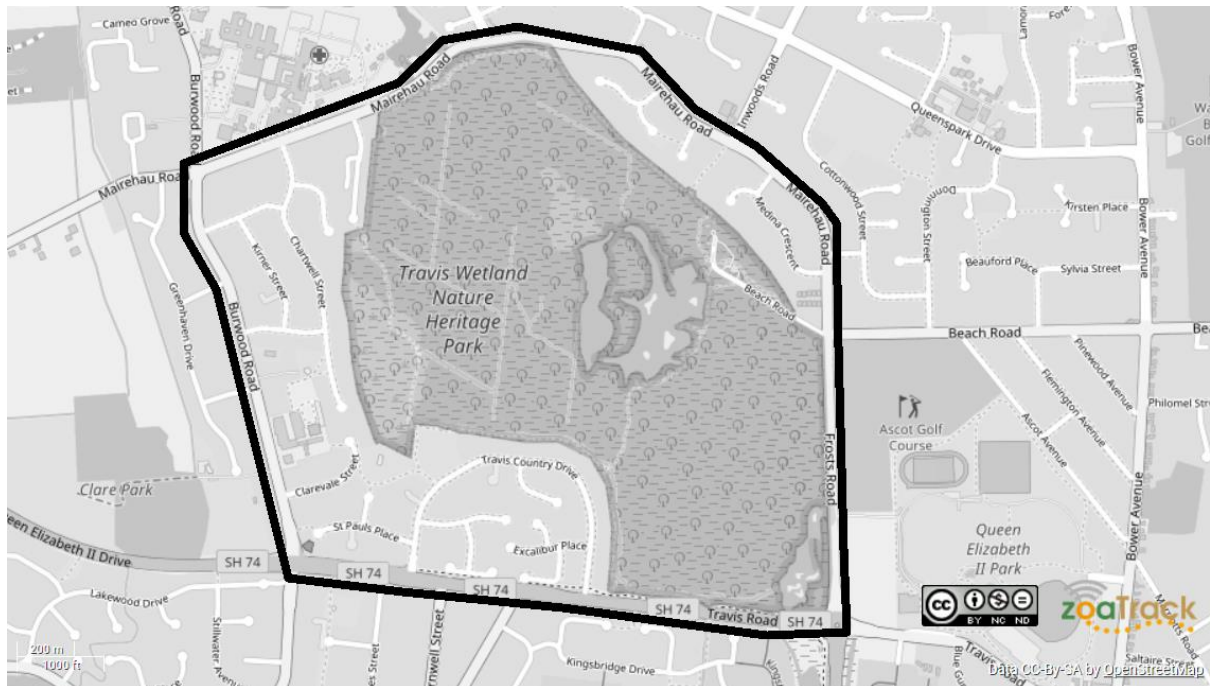


Figure 2.1. The 196 ha study area was defined by the space within the four main roads surrounding the Travis Wetland. These are Mairehau Road, Frosts Road, Travis Road, and Burwood Road.

2.3 Results

Cat Abundance and Density

One third of the approximately 715 houses in the area were systematically chosen for the door knock survey and letterbox drop, resulting in 231 houses being included. Of those houses, 178 (77%) responded and 53 (23%) did not. The door knock survey yielded 162 (91%) of the responses and the follow up mail survey resulted in 16 more responses (9%). The first round of the door knock survey between 2 - 6 pm resulted in 115 responses and the second round between 7 - 8.30 pm resulted in 47 responses.

A total of 64% of 178 households surveyed had no cats and 36% had one or more cat. It was most common for there to be one cat in the household (21%), followed by two cats (10%). Over the 178 houses surveyed, there was a total of 106 cats giving an average of 0.60 cats per household (Table 2.1). For the 36% of households with cats, the average number of cats was 1.66.

Table 2.1. Number of domestic cats in study area around the Travis Wetland.

No. of cats	No. of households surveyed	% of responses	Total cats
0	114	64	0
1	37	21	37
2	17	10	34
3	7	4	21
4	1	1	4
5	2	1	10
Total	178		106
Response	178	0.77	
No response	53	0.23	
Total	231		

There were approximately 715 total houses in the 196 ha study area. If it is assumed that the sample of households surveyed represents the study area, the total abundance of cats in the area is $715 \times 0.6 = 429$ cats. The density was estimated to be $429 \text{ cats} / 196 \text{ ha} = 2.19$ cats/ha.

Cat Characteristics

Of the 106 cats in the 178 households, 74 (70%) surveys about their characteristics were filled out. There was data on the breed for 64 of the cats. Mixed breeds were most common (54, 84%) and included Moggie (Moggy; either domestic shorthair or longhair), Domestic shorthair, Domestic longhair, and one Ragdoll/Moggie mix. Purebreds accounted for the rest of the cats (10, 16%) and each only occurred once or twice. Breeds included Abyssinian, Birman, British Shorthair, Exotic Shorthair, Norwegian Forest, Persian, Russian Blue, and Scottish Fold.

Colours were given for all 74 of the cats. Tabby cats were the most common (22%), followed by black and white (19%) and then plain black (14%). Ginger cats and grey cats were also common (both 9%). Tabby was often written as coat colour without specifying what colour.

Age was given for 73 of the cats. The age of cats showed a bimodal distribution (Figure 2.2). There was a high frequency of cats that were one year old or less, and many cats were two years old. A second peak occurred at 12 and 13 years old. The mean age was 7.86 years. The minimum age was 3 months and the maximum age of cats in the area was 18.

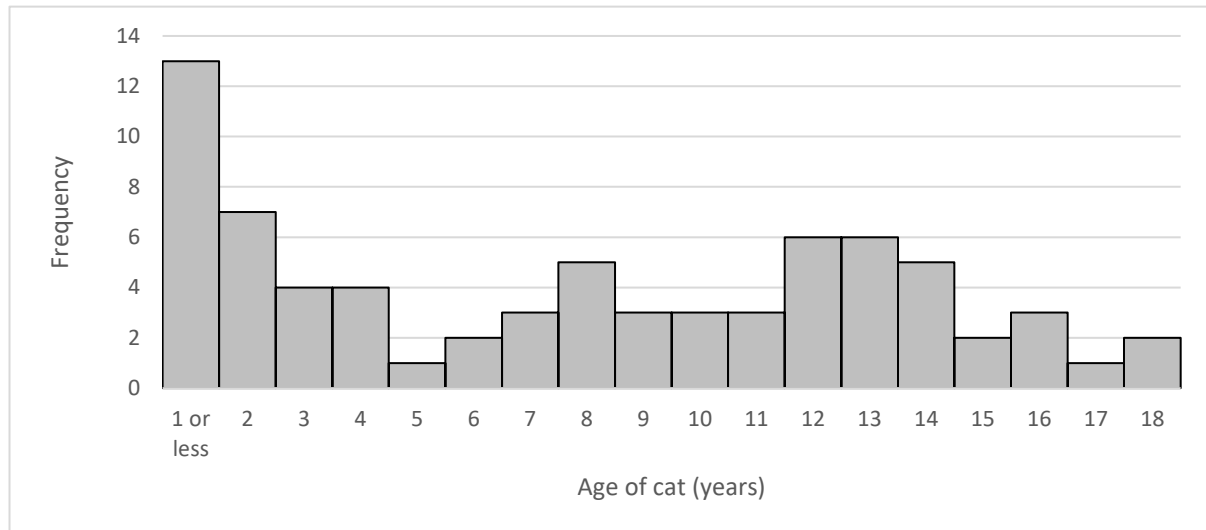


Figure 2.2. Age of 73 domestic cats (to the closest year) as reported in survey of Travis Wetland area.

There were 41 females (55%) and 33 males (45%) in my study. For the 74 cats, it was only unknown for one whether or not it was desexed. Only four cats were not desexed. Therefore, $69/73 = 95\%$ of the cats were desexed. Of the cats that were not desexed yet, one was 3 months old, two were 6 months old, and the other one was 11 years old. The age at which the cat was desexed was known for 58 cats (78%). The most common age for a cat to be desexed was 12 weeks old. Two cats were desexed at 3 years old, which was the oldest age for a cat to be desexed in this study.

Dry food was most frequently always available (42/72 cats, 58%) and wet food was most frequently given two times a day (26/72 cats, 36%). It was left out always for 8 different cats (11%). Giving scraps to a cat was a rare occurrence, with most cats not usually receiving any (40/52 cats, 77%). Some cats were given around one scrap a day (11/52, 21%), and one cat received about two scraps a day (2%). There was no answer for 22 of the cats.

There was data on reported hunting behaviour for 72 of the cats (Figure 2.3). Most people recorded their cats as never bringing home prey (28, 39%). It was less common for owners to note hunting behaviour frequency as fortnightly (3, 4%), weekly (5, 7%), or daily (3, 4%).

The frequency of reported hunting behaviour was not affected by whether the cat was a female or male ($U_{35,31} = 539.5$, $p = 0.97$). The frequency was also not affected by whether the cat was a mixed breed or purebred ($U_{46,9} = 220$, $p = 0.77$).

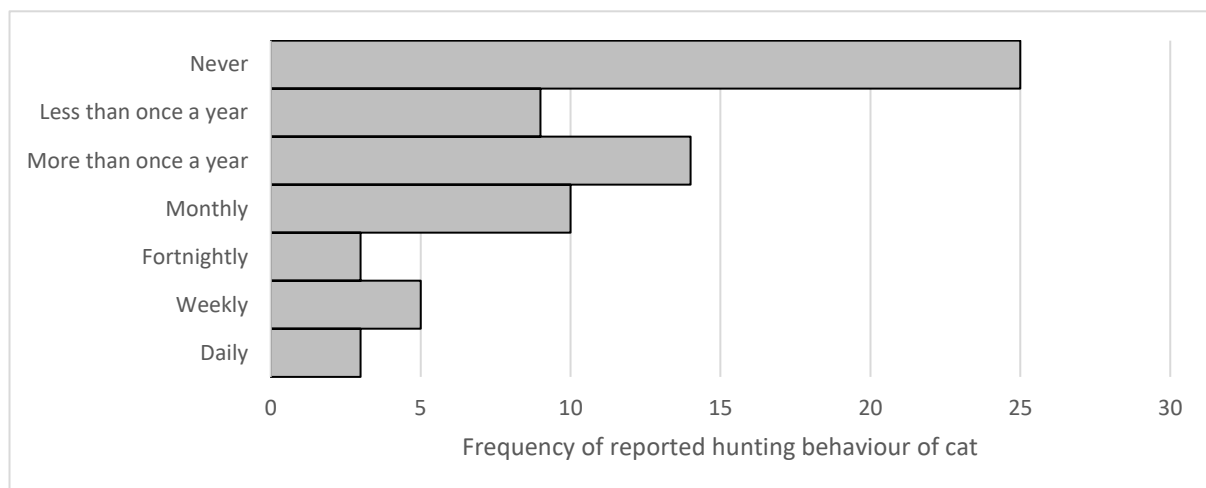


Figure 2.3 Frequency of reported prey brought home by the domestic cats, from surveys of owners near Travis Wetland area.

There was a significant negative correlation between cat age and reported hunting behaviour ($r_s = -0.46$, $df = 66$, $p = < 0.001$, Figure 2.4). Younger cats therefore were more likely to bring home prey more frequently.

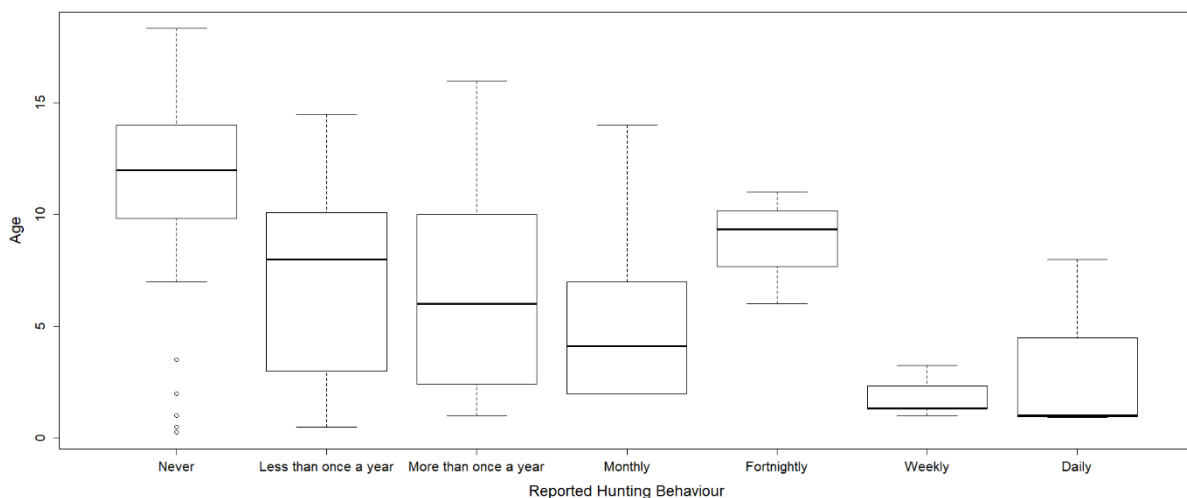


Figure 2.4. Age of domestic cats around the Travis Wetland compared with reported hunting behaviour by owners.

For the 74 cats, the most common movement restriction category of a cat was free roaming (72%), followed by locked in at night (23%). The only other category was indoor only with 4 of the 74 cats not allowed out (5%).

Out of 73 cats, 19 (26%) wore a collar all the time and 53 (74%) did not. One cat wore a collar with a bell sometimes. Of the 19 cats that wore a collar, 7 wore a bell (37%). The reported hunting behaviour response for cats that wore a bell were more than once a year four times, monthly twice, never for one cat, and fortnightly for the cat that sometimes wore a collar with a bell. There was no significant difference in reported hunting behaviour and whether the cat wore a bell or not ($U_{62,7} = 169.5$, $p = 0.33$).

There was reported range data for all 74 cats (Figure 2.5). The most common reported range the home owners had seen their cat cover was at the neighbour's property (32%). Cats were also frequently seen across the road (24%). Even though the majority of cats (72%)

were recorded as free roaming for movement restriction category, many were only ever seen at home (16%). Of the twelve cats seen at home only, seven (58%) were between the ages 12 and 18, one was less than one year old, and the other four were between ages 2 and 8. Out of 73 cats, 62 (85%) had not ever been seen at the Travis Wetland and 11 (15%) had been seen once or more. In some cases, the cats were seen daily there. The maximum reported range the cat had been seen by the owner was not affected by whether the cat was a female or male ($U_{38,33} = 605$, $p = 0.80$). The maximum reported range seen was also not affected by whether the cat was a mixed breed or purebred ($U_{50,10} = 261.5$, $p = 0.82$).

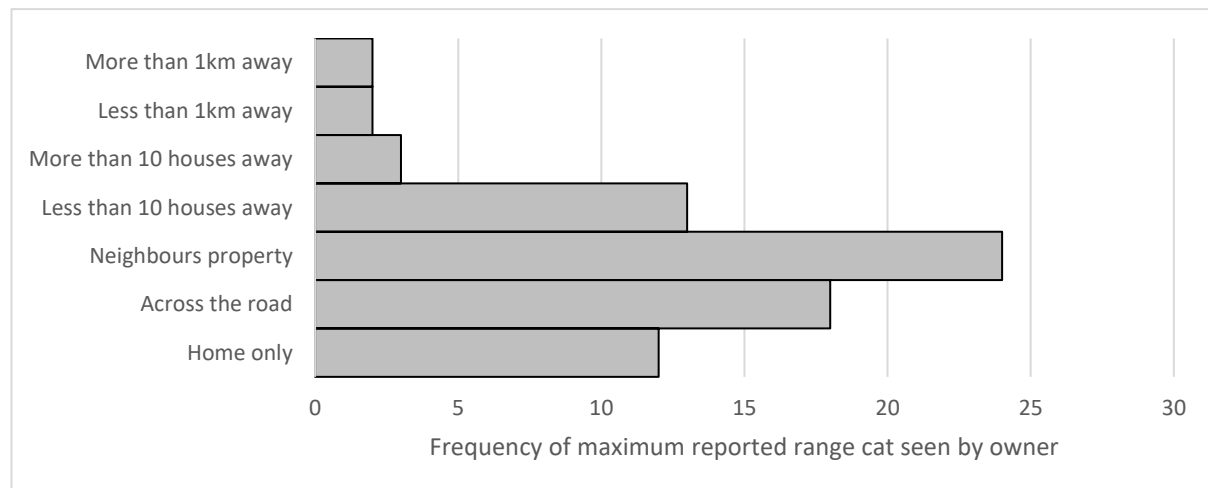


Figure 2.5. Frequency of maximum reported range domestic cats around the Travis Wetland had been seen by owner in the past.

There was no significant correlation between cat age and reported range seen from home ($r_s = 0.159$, $df = 71$, $p = 0.18$, Figure 2.6)

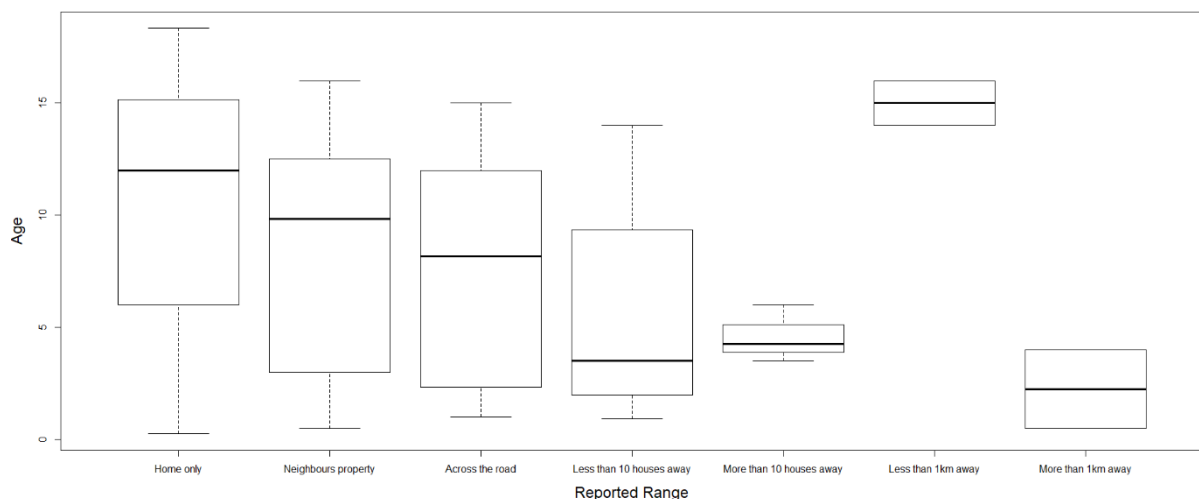


Figure 2.6. Age of domestic cats around the Travis Wetland compared with reported range by owners.

The maximum reported range that the cat was seen away from home (on a 7-point scale with more than 1km away = 1 and home only = 7) was compared with the frequency of prey brought home (7-point scale with never = 1 and daily = 7). There was no significant correlation between maximum reported range seen and prey frequency ($r_s = -0.09$, $df = 67$, $p = 0.46$).

2.4 Discussion

Density is important to estimate so extrapolations can be made about potential impact that domestic cats are having on wildlife in an area, especially for cats living near a natural reserve. The characteristics of cats, such as age, sex, breed, and movement restrictions, can be useful for further analysis. The reported hunting behaviour and range of the cats can be compared with research on their home range using GPS devices as well as more thorough noting down of prey items.

Abundance and Density

In 2018 compared with 2000, there were more households and fewer cats (617 increased to 715 households and 0.8 cats per household decreased to 0.6). Around half of New Zealand's households have an average of 1.8 cats (per cat-owning household), and in my study 36% of households had an average of 1.66 cats. A survey carried out in 1993 in Auckland estimated that 41% of households had on average 1.5-1.6 cats (Gillies, 1998). For the houses that have cats, the average number is similar to New Zealand wide and city estimates, but there were fewer houses with cats living near the Travis Wetland compared with the country wide average and the 50% result of Morgan (2002). In comparison, there are around 25% of households in Britain that have cats, around 30% in the United States, and 26% in Australia (Brickner, 2003), so cat ownership around the Travis Wetland is like the rest of New Zealand and still relatively high compared with overseas.

Having fewer cats in the area surrounding the Travis Wetland compared with in the past and elsewhere in New Zealand is potentially beneficial for the wildlife living there and may be reflective of increased understanding of the impacts of cats. For the 196 ha study area, the density of cats was 2.19 cats/ha (219 cats/km²) compared with the 2.52 cats/ha (252 cats/km²) in 2000. The Travis Wetland is 119 ha, so accounting for that and just using land with households, there were 429/119 ha = 3.61 cats/ha (361 cats/km²). A study in Bristol, UK estimated domestic cat density as 348 ± 86 cats/km² (Baker et al., 2008), whereas a University campus in Brazil feral cat density was estimated as 181.15 cats/km² in winter and 112.31 cats/km² in their summer sample (Campos et al., 2007). Closer to home, a Dunedin study estimated density as 223 cats/km² (van Heezik et al., 2010). On the extreme end of the scale, a Japanese study calculated adult feral cat density as approximately 23.5 cats/ha (2350 cats/km²) (Izawa et al., 1982). This was calculated from counting 200 individual cats that lived within the 0.085 km² village area located on a small fishing island. Many studies that include number and density estimates considered them as underestimates of actual numbers (Izawa et al., 1982), especially of total cat numbers as free-roaming cats were excluded from analysis. Thus, the density of domestic cats around the Travis Wetland was within the range seen globally.

Characteristics

Age of cats was recorded during the survey so that it could be used as a factor in further analysis. The low frequency of cats who are 5 or 6 years old could be explained by people not obtaining cats after the Christchurch earthquake. Those cats would have been born in 2012 and 2013. The low number of cats past 15 years old represents the life span of the cats in the area, with the max age being 18 years old.

For sex and neutering, in New Zealand it is not required that cats are desexed, but the majority were (95%) in my study. Fighting, roaming, and spraying are behaviours that decline after a male cat has been desexed (Fogel, 1991) so even though neutering a cat is not required, many owners make sure their cat has undergone the procedure. Morgan (2002) found 95% of cats desexed also, therefore its importance has been seen over many years.

Another question asked was how many times a day food was given. This did not account for how much food was given each time. Because of this, it causes comparisons to be inaccurate. The low response of scraps given per day may have been because of confusion about the question. Scraps meant food given to the cat that is meant for human consumption. The question was not asking about treats given. In the future, number of treats given could be included in the survey. The type of food and number of times a cat is feed each day are possible factors influencing prey retrieval, but Morgan (2002) found no significant effect between them and reported hunting behaviour by the owners. She did however find a significant correlation between them and prey retrieval, showing the hunting study was more accurate than the reporting done by the owners initially.

The high frequency of cats not bringing home prey may be representative of low numbers of wildlife in the area, or for other reasons such as the cat may not bring all their prey home or a one-off answer on a survey is imprecise compared to a 6 or 12 month long study. Chapter 4 investigates prey retrieval directly and goes into more depth on the factors affecting it.

The movement restrictions of cats were noted down during the survey as indoor only cats could not participate in further study, and the restrictions can be compared with results in Chapters 3 and 4 on home range and prey retrieval. There was a high proportion of cats in my study that were free roaming and 23% of the cats were locked in at night. Locking cats in at night may be detrimental to wildlife. Amphibians and mammals are often more commonly caught at night and birds and reptiles are often caught during the day (Barratt, 1995). It has been found that cats may prefer small mammals such as rats and mice (Barratt, 1995), and stopping them from hunting those at night may be encouraging increased hunting behaviour during the day. None of the cats in my study were kept in during the day and let out at night. This information will be discussed further in Chapter 4.

Only seven cats wore a collar with a bell in my study, and the wide variation of frequency of prey brought home by the different cats indicates a lack of hunting discouragement. There was no significant difference in reported hunting behaviour between cats wearing a bell or not. Many studies have looked at the effects of bells verse no bells on cat hunting behaviour and success rate. Varied results have been given, with some studies supporting bell use (Gordon et al., 2010), and others saying it has no effect (Calver et al., 2007; Morgan, 2002). Novel scrunchie BirdsBeSafe collars have also been tested as a bright colourful way to reduce hunting success (Calver et al., 2007; Willson et al., 2015). Chapter 4 discusses these methods as ways to reduce cat predation in more depth.

For reported range, there was a high frequency of free roaming cats, but many had only ever been seen at home. The cats only seen at home were more likely to be older cats (58% were ages 12 or older). Often owners do not notice where their cat is at all times, so this reporting of information is never as informative as GPS tracking. Chapter 3 provides GPS data on where cats went.

Conclusion

In New Zealand, cats are not required to be registered like dogs, and because of this there is no definite number of domestic cats. It is even more difficult to obtain number estimates of stray and feral cats. However, the numbers can be compared with other studies as they experience the same problem. The only significant correlation of characteristics was between cat age and frequency of reported hunting behaviour. This shows that younger cats were more prolific hunters compared with older cats. However, age had no effect on maximum reported range the cat had been seen from home. In the Morgan (2002) study, there was a positive correlation between maximum reported range that cats were seen and reported hunting behaviour frequency, but I did not find that here. Morgan (2002) had suggested the

correlation meant more prey are available further away from the cat's home and that the cats that enter the Travis Wetland may use it as hunting grounds. The lack of correlation now may indicate fewer wildlife available in general. From cat owner reports, there was a consensus that there has been less sighting of native birds, lizards, and other wildlife in the city compared with in the past. Nevertheless, owner opinion on prey retrieval and range is not a good substitute for detailed recording of prey and GPS tracking of cats (see subsequent chapters).

Chapter 3: Home Range

3.1 Introduction

Animal movement patterns show important aspects of the ecology of a species but can be difficult to record accurately (MacCurdy et al., 2011). Information about resource use, social interactions, and home range can be obtained from tracking animal movements (Fitzgerald & Karl, 1986). A range of animals have been tracked, including birds, mammals, and fish, to examine their habitat use, and to analyse their lifestyle and prey consumption behaviour (Kritzler et al., 2007; MacCurdy et al., 2011; Stienen et al., 2016; Voegeli et al., 2001). In the past, larger animals were easier to track but gradually with increasingly advanced technology, making smaller devices possible, smaller animals such as cats, mice, and birds can be tracked (Kikillus, Woods, et al., 2017; Kritzler et al., 2007; MacCurdy et al., 2011; Recio et al., 2011; Rerucha et al., 2017; Stienen et al., 2016). There is a relationship between home range area and body size in mammals and carnivores have larger home ranges than herbivores of the same size (Lindstedt et al., 1986). Understanding predator ecology is important for conservation both because many predator species are threatened with extinction but also because some introduced predators are themselves a threatening process to endemic wildlife. Tracking predator movement enables home range estimation which in turn provides information on their potential ecological effects, particularly their impact on the food chain. In New Zealand, as in some other areas, domestic cats have no natural predators and are only limited by their lifestyle and own experience in catching wildlife (Kauhala et al., 2015). New Zealand fauna have not been able to coevolve extensively with introduced predators such as cats, possums, and rodents (Gillies, 1998).

The home ranges of cats vary depending on habitat, as well as factors such as time of day and season. Home ranges of domestic cats can be small in urban areas (e.g. Japan, 0.1-1.8 ha) (Izawa et al., 1982). On Stewart Island, New Zealand, domestic cat home ranges were between 0.05 ha (typical property size) for cats that never left their backyards and 16.58 ha (Wood et al., 2016). Feral cats in less developed areas such as the Trounson Kauri Park, New Zealand, have much larger home ranges, between 31.4 ha to 688.4 ha (Gillies, 1998). Males usually have larger home ranges than females, but it is a non-significant difference (Barratt, 1997; Fitzgerald & Karl, 1986; Gillies, 1998; Izawa et al., 1982; Langham & Porter, 1991; Meek, 1998b; Turner & Mertens, 1986). Male cats compete for access to females, and may have to venture further to do so, while females primarily compete for food (Barratt, 1997; Morgan, 2002). Gillies (1998) found that adult males had larger home ranges than subadult males, but adult females had smaller home ranges than subadult females. Subadults need more nutrients for growth and the young females lacking hunting skills may have to hunt over larger areas (Lindstedt et al., 1986). Barriers such as roads, and perhaps water, often restrict how far a cat will go (Barratt, 1997). Previous studies have reported larger home range areas of cats during the night compared with the day with only some individuals being more active during the day (Alterio & Moller, 1997; Barratt, 1997; Langham & Porter, 1991; Page et al., 1992), although this is not always the case (van Heezik et al., 2010). Along with many cat's home ranges depending on time of day, seasonality also plays a role. For example, during winter cats may be more active during the middle of the day when it is warmest (George, 1974). Consequently, there is high variability in home range size within and between individuals.

In New Zealand, cats that are free roaming and active during the day and at night may pose a threat to native wildlife. Most skinks have diurnal activity with only some being

nocturnal (Alterio & Moller, 1997). Barratt (1997) and Meek (1998a) found that cats killed more rodents during the night and more birds and reptiles during the day. If cats were to be kept indoors at night, an increase in rodent control would be necessary (Barratt, 1997; Meek, 1998a). This may vary between areas due to the relative abundance of different wildlife.

Research suggests around 60% of cats that live near woodland/forest habitat will go into those areas (Barratt, 1997). In Dunedin, New Zealand, one study found that the home ranges of domestic cats living near bush areas was not significantly larger than cats that lived further away (van Heezik et al., 2010). They found that cats that lived closer to the edge of town had significantly larger home ranges compared with suburb cats or cats living close to bush areas (van Heezik et al., 2010). But they did not bring home significantly different amounts of birds. But Barratt (1998) found that more prey was caught by cats living near rural, grassland, and forest areas compared with suburban areas. Therefore, the demography of the cat population could interact with the surrounding habitat to determine habitat use and home range area.

The New Zealand city of Christchurch consisted of huge expanses of wetlands in the 1850s (Morgan, 2002). Since the 1990s, the Travis Wetland is the last large area of wetland in the city (Morgan, 2002). The area is a haven for many wetland birds. There are more than 700 pukeko that use the wetland, which is around half of Christchurch's pukeko population (Morgan, 2002). To protect the wildlife that reside in the Travis Wetland, predators need to be reduced or excluded (Morgan, 2002). There are multiple small mammal traps set out throughout the wetland, which are regularly checked by the Christchurch City Council park rangers (pers. comm.). However, despite having built a moat around the wetland, cats can still have access by jumping or swimming across (Morgan, 2002). It is therefore vital to understand cat use of the area for management of potential impacts.

In an earlier study, Morgan (2002) used 10 radio transmitter collars rotated between 21 neutered cats to estimate their use of the wetland. Each cat was located every hour over a 4 to 6-hour shift, once a week, for 4 weeks. This method of locating cats is labour- and time-intensive as it requires physical proximity to accurately measure range. At the time of the study GPS collars were too expensive to use and had high levels of error. Currently GPS collars are cheaper and more accurate. Van Heezik et al. (2010) used 125 g Sirtrack® GPS collars on 16 cats that lived at the edge of a native forest and 16 that lived in fully urban areas in Dunedin. Compared with radio-tracking, the GPS system has fewer technical problems from signal interference and data is obtained remotely so is less labour-intensive (van Heezik et al., 2010). A more recent study during 2015 and 2016 used "Mobile Action i-gotu USB GPS Travel Logger" devices to track domestic cats in Wellington (Kikillus, Woods, et al., 2017). These devices are lighter (20 g) than Sirtrack® GPS collars, less expensive, and can be attached to a harness taking weight off from the cat's neck while keeping cat movement unrestricted. Over 200 cats were tracked successfully in Wellington and many more cats have been tracked overseas with the travel logger device (Kikillus, Woods, et al., 2017).

In my study, the GPS devices used by Kikillus et al. (2017) were fitted to determine the home range size and movements of domestic cats in the same Travis Wetland study area as Morgan (2002). There were fewer cats in the area (Chapter 2) and significantly fewer cats/household during my study than there were in the previous one. Population density of cats may affect their home range areas (Morgan, 2002), so home ranges may be larger with fewer cats, and this could be because their defended areas (territories) are more spread out as seen in other areas (Bradshaw, 1992; Morgan, 2002). With less competition, cats may have increased access to the wetland. Therefore, I hypothesised that home range areas would be larger compared to those measured by Morgan (2002).

3.2 Methods

Small GPS devices (Mobile Action i-gotu USB GPS Travel Logger) were used to track domestic cats (<http://www.expansys.co.nz/mobile-action-i-gotu-usb-gps-travel-logger-gt-120-178536/>). Seven GPS collars were rotated between volunteering participants. After households showed an interest in taking part of the cat range study, a harness was trialled on their cat. The GPS devices were attached to a harness between the shoulder blades so that cat movement was not restricted and so the device faced the upwards for increased satellite accuracy. Only cats that were comfortable with the harness on were used in the study. Following previous research, cats wore the harness for 7 days at a time (Kikillus, Woods, et al., 2017; van Heezik et al., 2010). The first full day with the harness on was an acclimatisation day, with the following six days used for data analysis (Kikillus, Woods, et al., 2017; van Heezik et al., 2010). A location waypoint was obtained approximately every 3 minutes. Location data was accessed by connecting the GPS device to a computer once the device was removed after 7 days. Tracking of the first cat started on the 21st of April and the final day of tracking the last cat was the 2nd of August.

The home range size for each cat was defined by 100% minimum convex polygons (MCPs/polygons) for comparison with Morgan (2002). Additionally, 95% and 50% polygons were used as 95% is more robust by removing outliers and 50% is used to show their core area where they spend a large portion of their time. Day and night polygons were also calculated; day time was defined as 6.00 am to 5.59 pm. The home range areas were calculated on R using the “adehabitatHR” package. Latitude/longitude data was first converted into degrees minutes seconds (DMS). The Land Information New Zealand website (<http://apps.lin.govt.nz/coordinate-conversion/>) was then used to convert WGS1984 DMS information to NZ grid system “northing and easting” meters data. The polygon images were created on Zoatrack (<https://zoatrack.org/>), a free animal tracking software and Movebank (<https://www.movebank.org/>), another free tracking database. The effect that the characteristics sex and age of the cats had on home range were tested on R using ANOVA (F test) and GLMMs using R package lmer with cat ID as a random factor (t test). Pearson's product-moment correlation (r_p) was used to test the effect of distance of household from the wetland periphery. Figure 3.4 shows the Travis Wetland boundary which was used to define the distance between households and the wetland periphery.

Outlier Removal

Before analysis of the data, manual checks were carried out for the removal of outliers. The GPS may have random errors as it cannot obtain accurate fixes when inside or obstructed by objects (Vazquez-Prokopec et al., 2009). The device needed to face the sky to improve satellite signaling (Vazquez-Prokopec et al., 2009), which was achieved by sitting it in between the shoulder blades of the cat, but it often slipped to one side which provided more natural movement for the cat. The parameters for removal were determined *a priori* as they were less likely to represent real waypoints. First, 99% MCP images were created on Zoatrack to see if there were any waypoints that looked like potential outliers. These were waypoints that were more than around 100m out from the edge of the MCP, had no other waypoints nearby, and had there and back trajectories following a similar path. The coordinates of 28 waypoints were noted down that filled the brief. Next, Pythagoras' theorem was used to work out the actual distance travelled between each waypoint directly before and after the potential outlier. Using that distance and the time between each waypoint, the speed of the cat was calculated. A decision was then made about whether the cat could have reasonably travelled the distance within the time period, also taking into account the altitude of the waypoint which can indicate if it is a random GPS error.

Only two waypoints of GPS data were removed, both from the same cat (“Max”) (Figure 3.1). The first had an average speed of 7.33 km/hr to get to the waypoint 464.48 m away (3 minutes 48 seconds) and then 8.28 km/hr to get to the subsequent waypoint 464.6 m away (3 minutes 22 seconds). The trajectory was straight, and the altitude went from -0.35 m to 1136.49 m to -14.63 m. This was the only waypoint location in the central area of the wetland so the decision to remove it was not taken lightly. The walking speed of a cat is between 4.5 km/hr and 5.4 km/hr. It seemed implausible that Max ran to that waypoint in the wetland, did not spend any time there, and ran back all while crossing wide water moats and the knee-deep swamp water of the wetland. The second excluded waypoint was in the urban area to the south, across a busy road, and had an average speed of 5.98 km/hr to get to the waypoint 338.89 m away (3 minutes 24 seconds) and 49.84 km/hr to get to the subsequent waypoint 346.13 m away (25 seconds). The trajectory was straight, and the altitude went from 7.1 m to 94.87 m to -21.97 m. The fastest domestic cat breed has a top speed of 48 km/hr. It is therefore implausible that Max could have an average speed higher than that.

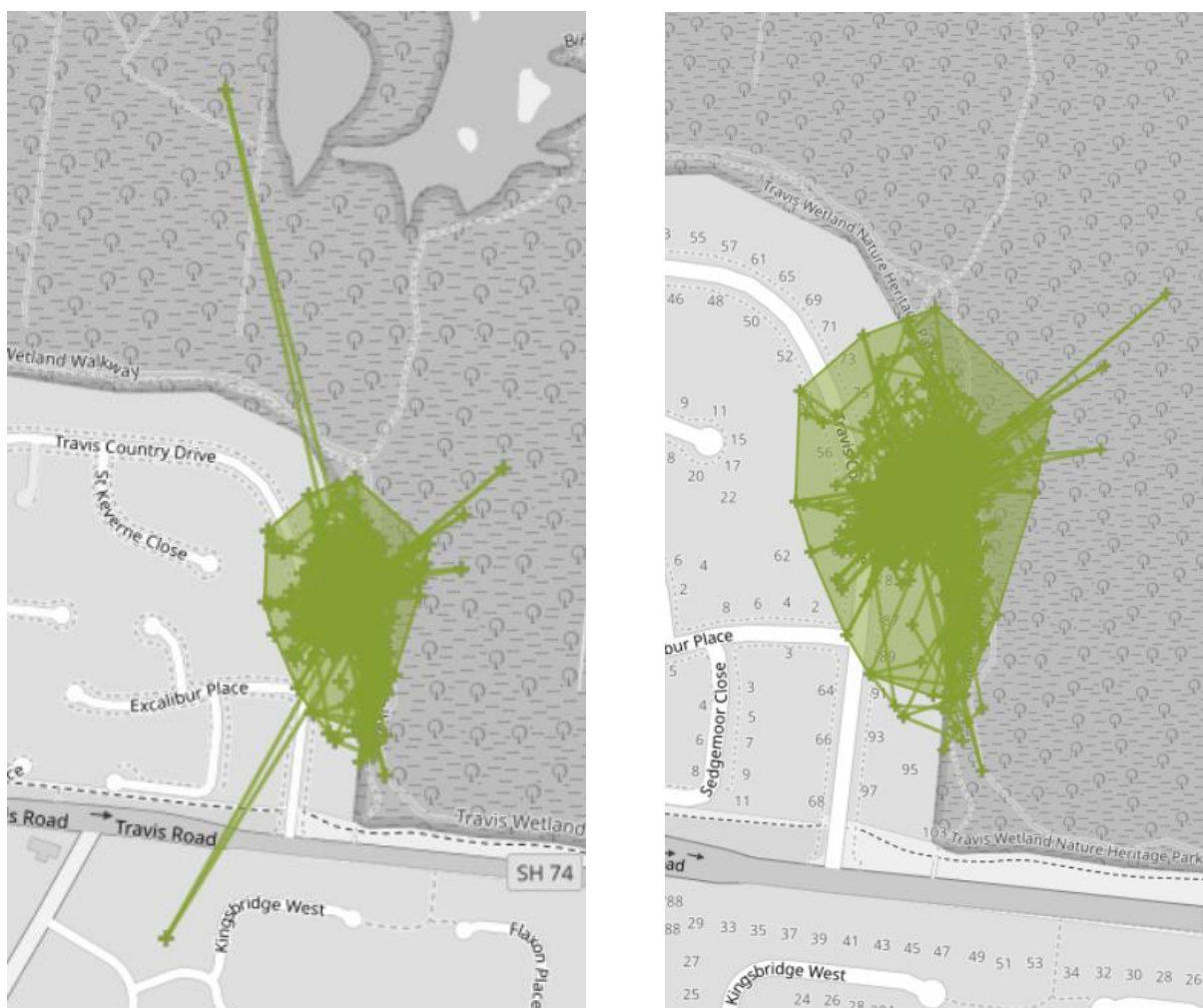


Figure 3.1. The 99% MCP from Zoatrack (Google Maps) of Max showing the top and bottom outliers that were removed before analysis of the data on the left. On the right is the same tracks with the outliers removed.

For one cat, Munchkin, tracking had to be repeated. Before analysis of the data, her first tracks were discarded, and the second ones were used (Figure 3.2). The first tracks appeared to show the cat moving large distances, including across busy roads, whereas Munchkin spent a lot of time inside (they had just only recently moved into the house) so that may have caused extensive GPS errors. The homeowners explained their cat could not have been outside at certain times as they knew for certain she was inside. The second set of tracking gave more plausible results (Figure 3.2).

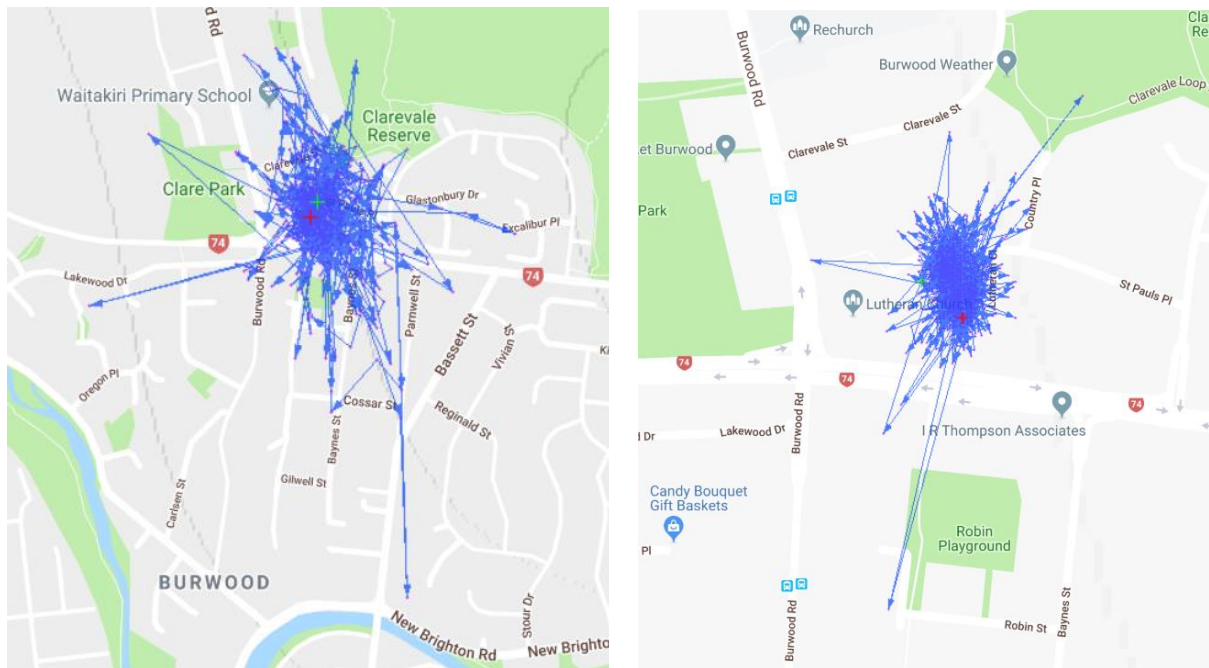


Figure 3.2. Images from Movebank (Google Maps). On the left are the original Munchkin tracks and on the right are the results of the second-time tracking. Note smaller scale of the second map.

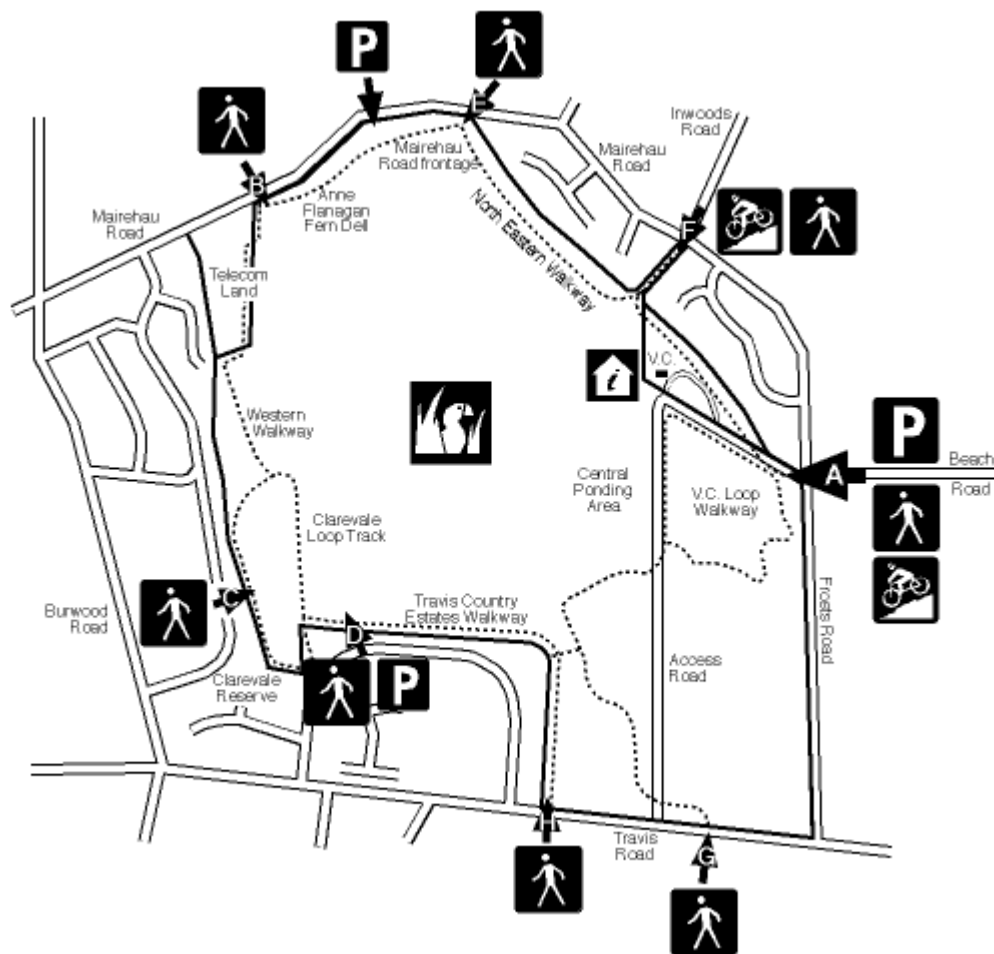


Figure 3.4. The Travis Wetland boundary used to define the distance of households to wetland periphery (<https://my.christchurchcitylibraries.com/travis-wetland/>, November 2018).

3.3 Results

Home Range Area Estimates

A total of 12 households with 14 cats participated in this tracking study. Information about the 14 cats and their home range areas are given in Table 3.1. Bella (ID47), Maxi (ID13), Millie (ID25), and Oscar (ID39) were confined to their households at night and the other 10 cats were free roaming. There were between 725 and 3049 GPS fixes for each cat, with a mean of 1942 and median of 1793. Full MCP home range areas were between 1.34 and 9.69 ha (Figure 3.6). There were 11 out of 14 cats that had home range sizes between 1 and 5 ha. Only three cats had home range sizes larger than 5 ha. Information about total distance travelled, the maximum distance the cats moved away from their household, and the distance of the household to the wetland is provided in Table 3.2.

Tigger had the largest home range area (9.68 ha), which resulted from his (slow and well documented) journey to another house far away (Figure 3.7). The cat with the smallest home range area, Roxy with an area of 1.34 ha, lives in the same household as Tigger. She and Tigger are both young 2-year-old cats.

Table 3.1. Cat home range participants. Age is closest year from given specific age. Sex is M for male and F for female. 1|mixed breed and 0|pure breed. 100% area is 100% MCP area (ha), 95% area is 95% MCP (ha), and 50% area is 50% MCP (ha)

Name	Cat ID	Age	Sex	Breed	Detections	100% area	95% area	50% area
Batman	62	4	M	0	2594	3.54	0.76	0.04
Bella	47	1	F	1	1826	2.15	0.51	0.08
Cooper	74	9	M	1	2028	5.69	1.04	0.12
Hunter	28	2	M	0	1245	3.75	0.53	0.09
Max	11	8	M	1	1758	3.62	1.14	0.07
Maxi	13	1	M	1	2770	8.29	1.16	0.09
Mika	59	1	M	1	3030	2.51	0.56	0.05
Millie	25	6	F	1	2983	3.26	0.54	0.04
Munchkin	57	4	F	1	1584	4.51	0.63	0.10
Nina	29	3	F	0	1488	3.14	0.91	0.09
Oscar	39	14	M	1	1153	3.53	0.58	0.05
Poppy	69	2	F	1	3049	2.27	0.26	0.03
Roxy	42	2	F	1	725	1.34	0.42	0.07
Tigger	41	2	M	1	955	9.68	3.40	0.09
Maximum					3049	9.68	3.40	0.12
Minimum					725	1.34	0.26	0.03
Mean					1942	4.09	0.89	0.07
Median					1792	3.54	0.61	0.08

Table 3.2. Distance travelled by cat over the 7 days wearing the GPS, maximum distance travelled away from house (to the nearest 5 m), and distance of household to the wetland.

Name	Distance travelled (km)	Maximum distance (nearest 5m)	Distance of household to Wetland
Batman	43.09	135	80
Bella	32.09	120	225
Cooper	43.08	240	25
Hunter	25.33	360	240
Max	39.81	190	20
Maxi	56.77	310	230
Mika	51.14	135	130
Millie	49.52	225	20
Munchkin	32.27	280	260
Nina	27.00	165	240
Oscar	25.83	180	30
Poppy	47.25	125	200
Roxy	12.41	90	90
Tigger	17.52	455	90
Maximum	56.77	455	260
Minimum	12.41	90	20
Mean	35.94	215	
Median	36.04	185	

Figure 3.5 shows the trajectories and waypoints for the 14 cats, demonstrating the trips that the cats took away from home. Most of the time the domestic cats stayed in a set area around their household and only occasionally made a trip further away.

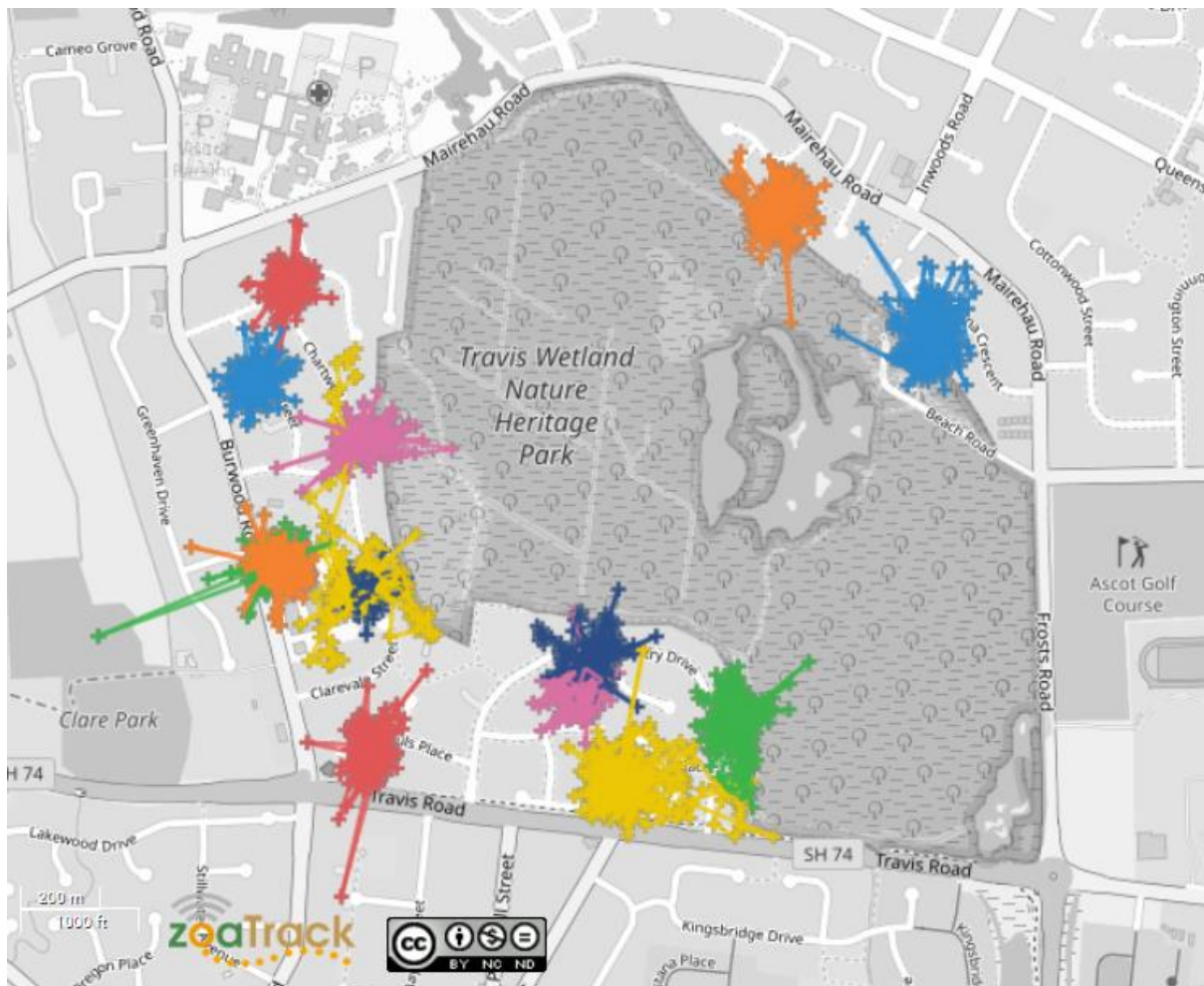
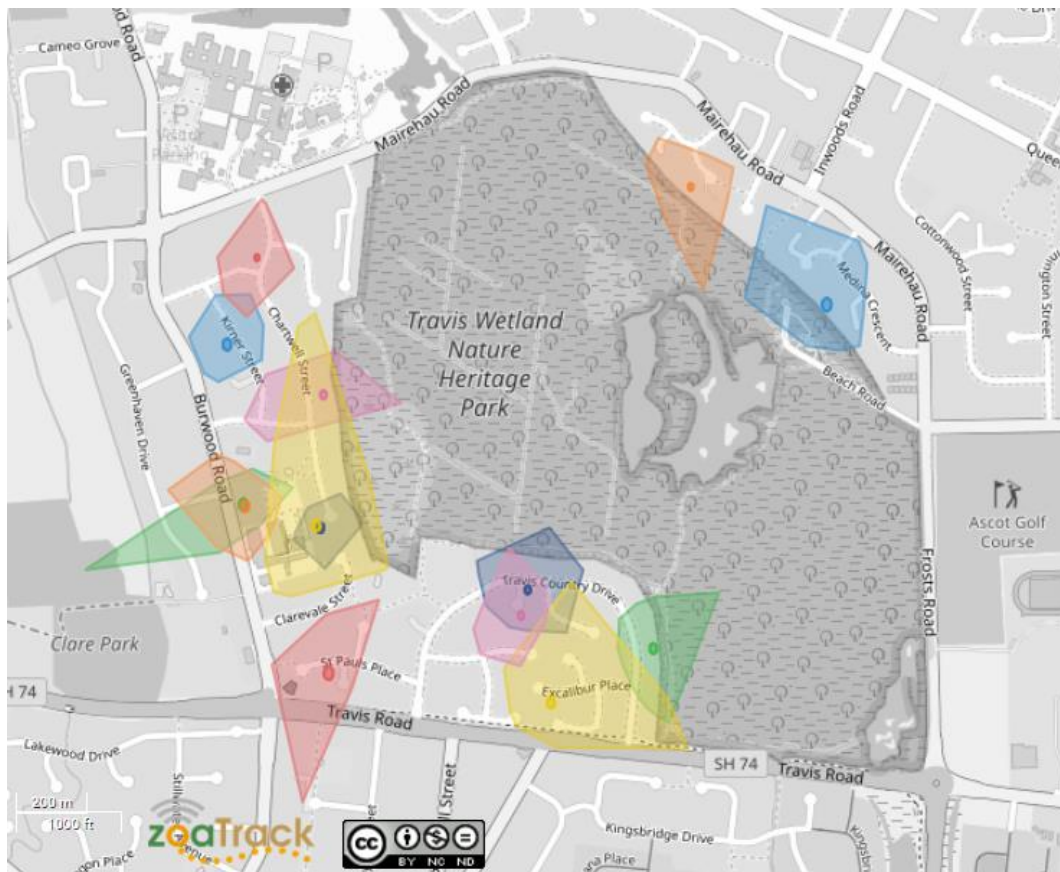


Figure 3.5. Trajectories and waypoints for the domestic cats around Travis Wetland from Zoatrack (Google maps). Batman/ID62 (dark blue right), Cooper/ID74 (light blue right), Oscar/ID39 (pink left), Hunter/ID28 (green left), Nina/ID29 (orange left), Maxi/ID13 (yellow right), Bella/ID47 (light blue left), Mika/ID59 (pink right), Tigger/ID41 (yellow left), Roxy/ID42 (dark blue left), Munchkin/ID57 (red bottom), Millie/ID25 (orange right), Poppy/ID69 (red top), and Max/ID11 (green right).

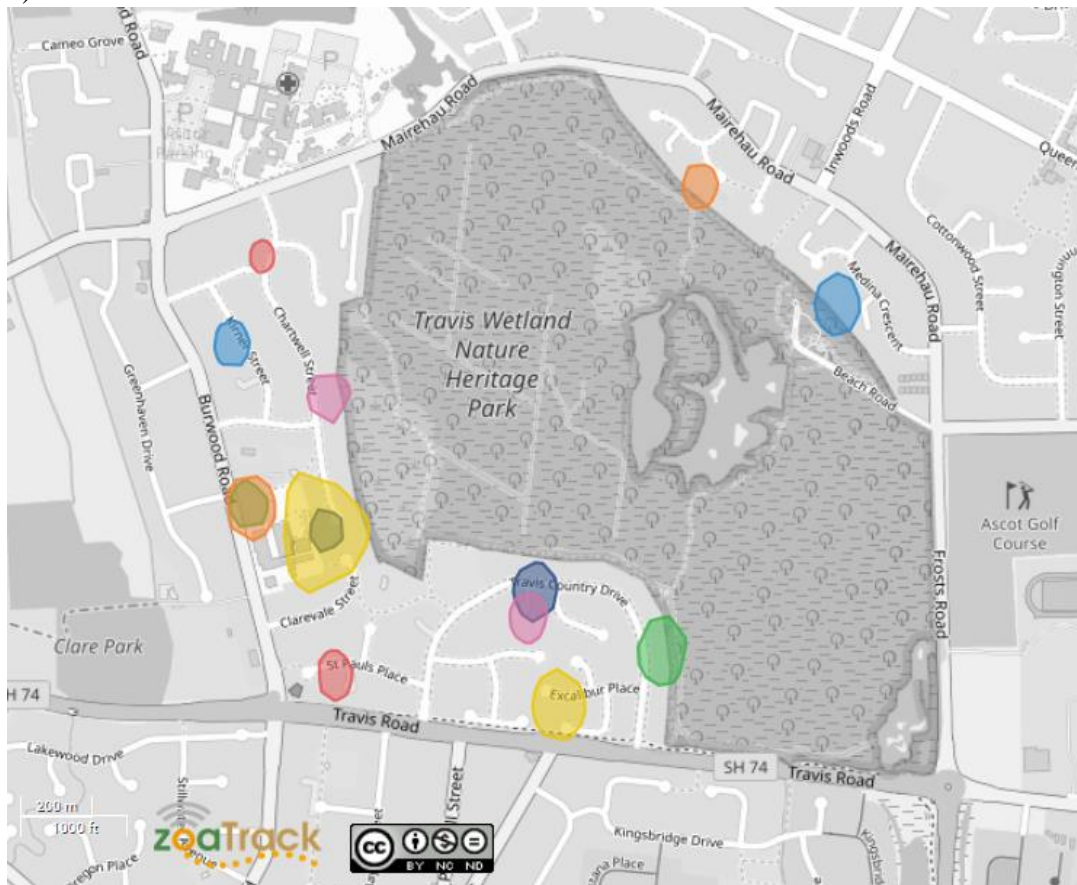
a)



b)



c)



d)

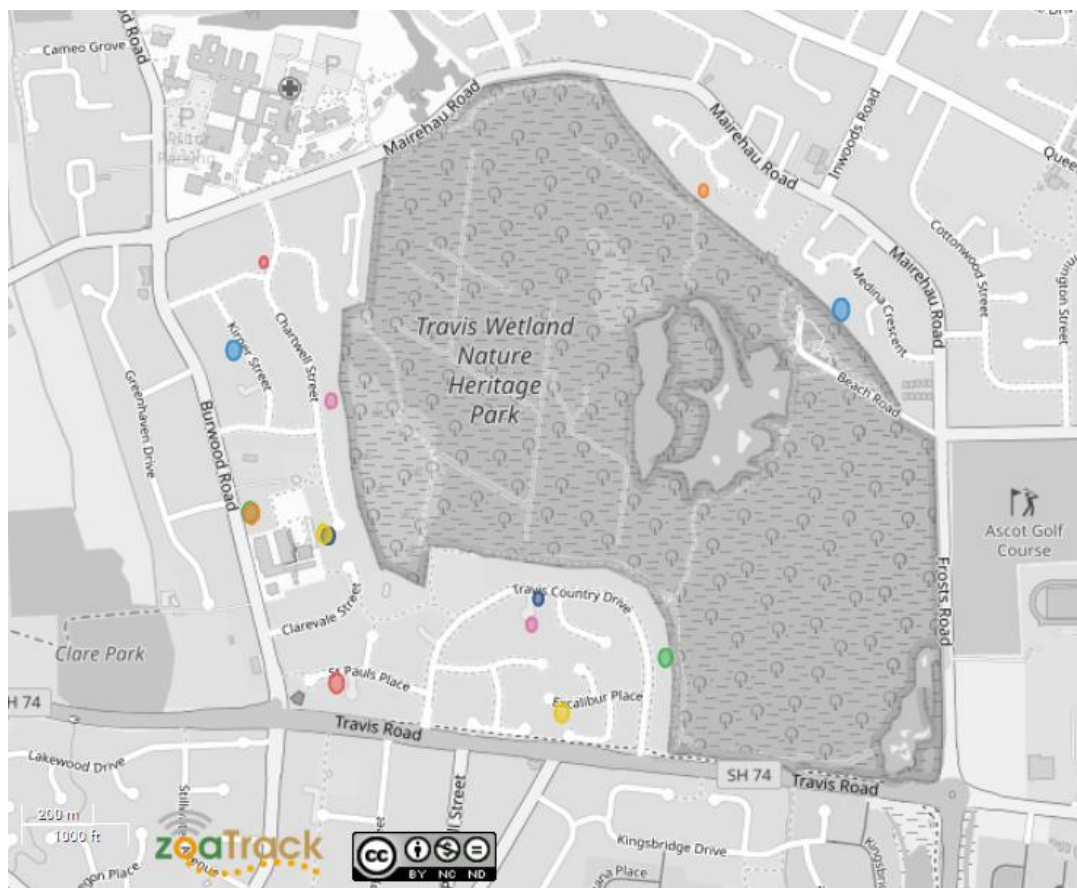


Figure 3.6. Home range areas from Zoatrack (Google maps) for the 14 cats. a) 100% MCP using grayscale background, b) 100% and 25% MCP to show household location, c) 95% MCP, and d) 50% MCP. Batman/ID62 (dark blue right), Cooper/ID74 (light blue right), Oscar/ID39 (pink left), Hunter/ID28 (green left), Nina/ID29 (orange left), Maxi/ID13 (yellow right), Bella/ID47 (light blue left), Mika/ID59 (pink right), Tigger/ID41 (yellow left), Roxy/ID42 (dark blue left), Munchkin/ID57 (red bottom), Millie/ID25 (orange right), Poppy/ID69 (red top), and Max/ID11 (green right).

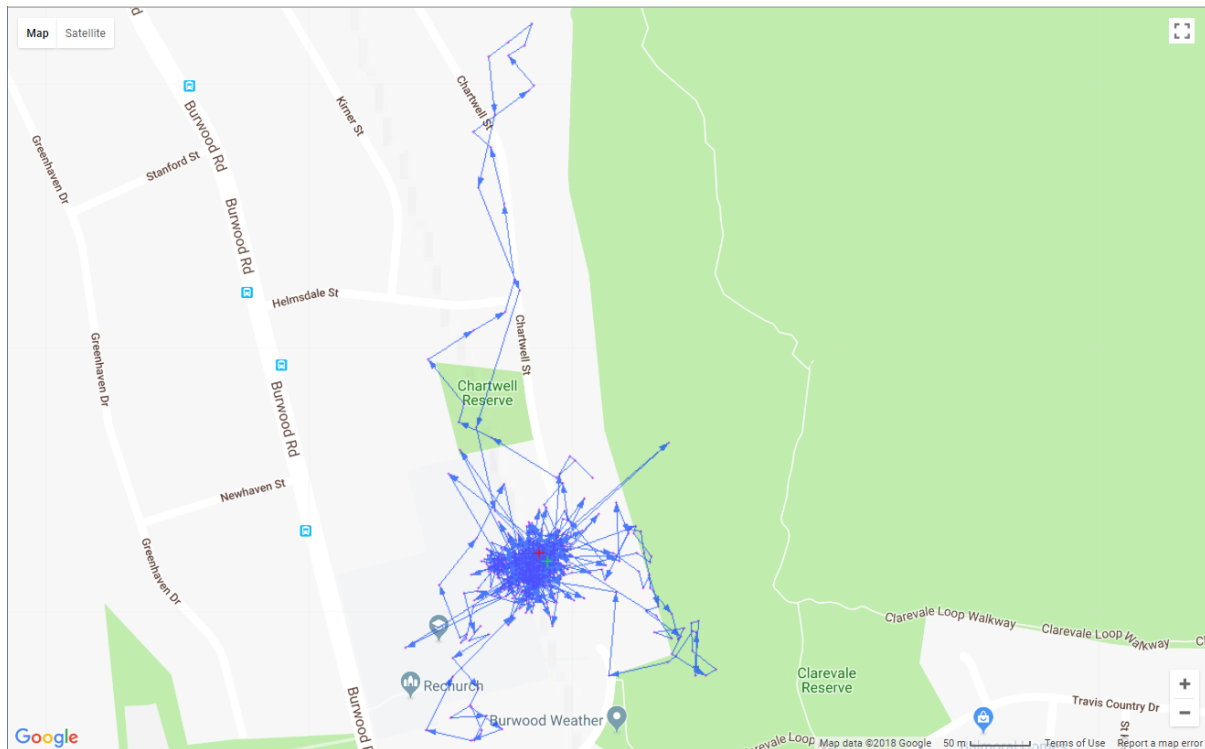


Figure 3.7. Tigger's 100 MCP home range area from Movebank (Google Maps).

Effect of Cat Characteristics on Home Range Area

Sex and age were analysed with total cat home range areas for 100, 95, and 50% MCP to see what may affect home range area. The areas underwent a transformation of log₁₀ to normalise the data.

The average home range area for 100% MCP of female cats was 2.78 (median 2.70) and of male cats 5.08 (median 3.69). Ages ranged between 1 and 14 years old. The mean was 4.21 and the median was 2.5 years old. Using an ANOVA, for the 100% MCP, sex had a significant effect of home range area ($F = 5.62$, $df = 1, 10$, $p = 0.039$). Age did not have a significant effect ($F = 0.04$, $df = 1, 10$, $p = 0.85$) and the interaction between sex and age did not have a significant effect ($F = 2.20$, $df = 1, 10$, $p = 0.17$). For the 95% and 50% MCPs, there was no significant effect of age ($F = 0.14$, $df = 1, 10$, $p = 0.72$; $F = 0.09$, $df = 1, 10$, $p = 0.77$), sex ($F = 3.89$, $df = 1, 10$, $p = 0.08$; $F = 0.21$, $df = 1, 10$, $p = 0.66$), or the interaction ($F = 0.47$, $df = 1, 10$, $p = 0.51$; $F = 0.16$, $df = 1, 10$, $p = 0.70$). Therefore, sex significantly influenced home range at the 100% MCP level, but age had no significant effect.

Effect of Time of Day on Home Range Area

Table 3.3 shows the home ranges for at night and during the day for the 14 cats. Analysis was carried out on the night and day home ranges for the 10 free roaming cats, excluding the four that were kept indoors at night. I ran GLMMs which had a random term for cat. For the 100% MCP there was a significant sex by time interaction ($t = 2.35$, $df = 8$, $p = 0.047$) as

shown in Figure 3.8. However, there was no significant interaction for the 95% and 50% MCPs ($t = 0.56$, $df = 8$, $p = 0.59$; $t = 0.25$, $df = 8$, $p = 0.81$). Therefore, home range area depended on sex of cat at the 100% MCP level, with males having a larger home range area at night. This was significant at 100% and not at 95% or 50% MCPs because of occasional long-distance movements by males. An example of that movement is shown by Tigger in Figure 3.7.

Table 3.3. Daytime and nighttime home ranges (ha) for GPS tracked cats. Day time was defined as 6.00 am to 5.59 pm. Sex is M for male and F for female. Area is the minimum convex polygon measurement (hectare). *Bella (ID47), Maxi (ID13), Millie (ID25), and Oscar (ID39) were locked in at night. The other 10 cats were free roaming.

Name	Age	Sex	100% day	100% night	95% day	95% night	50% day	50% night
Batman	4	M	2.28	2.10	1.11	0.29	0.06	0.03
Bella*	1	F	1.66	1.70	0.59	0.40	0.09	0.08
Cooper	9	M	2.96	4.09	0.93	0.91	0.10	0.14
Hunter	2	M	1.72	3.03	0.45	0.49	0.12	0.07
Max	8	M	5.91	5.96	0.53	1.64	0.06	0.09
Maxi*	1	M	4.31	5.68	0.59	1.80	0.07	0.10
Mika	1	M	1.25	2.39	0.53	0.52	0.05	0.04
Millie*	6	F	2.49	2.37	0.74	0.33	0.05	0.03
Munchkin	4	F	3.97	1.58	0.60	0.57	0.10	0.10
Nina	3	F	2.89	1.46	0.88	0.82	0.08	0.07
Oscar*	14	M	2.14	2.34	0.38	0.59	0.04	0.05
Poppy	2	F	1.36	2.07	0.23	0.28	0.03	0.03
Roxy	2	F	0.84	1.02	0.42	0.31	0.07	0.05
Tigger	2	M	4.34	8.99	1.06	5.85	0.08	0.19
Maximum			5.91	8.99	1.11	5.85	0.12	0.19
Minimum			0.84	1.02	0.23	0.28	0.03	0.03
Mean			2.72	3.20	0.65	1.06	0.07	0.08
Median			2.38	2.35	0.59	0.54	0.07	0.07

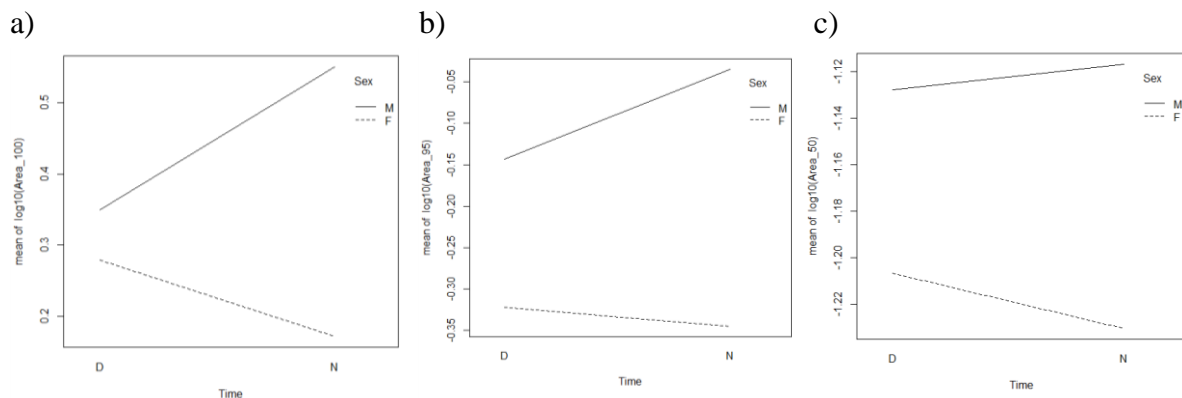


Figure 3.8. Mean home ranges ($\log(\text{ha})$) of GPS tracked cats compared between 10 male and female free roaming cats for day and night time. A) 100% MCP, b) 95% MCP, and c) 50% MCP.

Habitat Use

For the 100% area MCP, 9/14 (64%) cats entered the wetland to the periphery. These were Millie/ID25, Cooper/ID74, Max/ID11, Batman/ID62, Mika/ID59, Maxi/ID13, Oscar/ID39, Tigger/ID41, and Roxy/ID42. However, for the 95% MCP only 5/14 (36%) of the cats reached the periphery. These were Millie, Cooper, Max, Oscar, and Tigger. None of the cats reached the centre of the Travis Wetland.

Effect of Distance of Household to Wetland Periphery

Distance of cat's household to the wetland (measured to the nearest 5 m) had no effect on home range area. The 100% area was not correlated with distance ($r_p = -0.01$, $df = 12$, $p = 0.97$). Nor was the 95% area ($r_p = -0.18$, $df = 12$, $p = 0.53$) or the 50% area ($r_p = 0.25$, $df = 12$, $p = 0.39$).

Estimation of Number of Cats Using Travis Wetland

Table 3.4 shows information about the number of cats that enter the Travis Wetland. There were 9/14 cats that entered the wetland, including all four of the cats that live at the wetland periphery. Half of the cats not living at the periphery entered the wetland. Based on estimates of how many cats there are per household (Chapter 2), it is estimated that between 245 and 275 cats may enter the wetland. The lower estimate is combining the 60 estimated cats that live on the periphery and the 185 estimated cats which is half of the cats that live in the rest of the study area. The upper estimate is the 64% 9/14 cats that entered the wetland.

Table 3.4. Estimates of domestic cats entering the Travis Wetland from within the 196 ha study area.

Area	Number of households	Estimated number of cats	Number of cats tracked	Number that entered wetland	Percentage	Estimated total entering wetland
Periphery of wetland	100	60	4	4	100%	60
Rest of study area	615	369	10	5	50%	185
Total study area	715	429	14	9	64%	275

3.4 Discussion

Benefits and Shortcomings of GPS Tracking

The Mobile Action i-gotu USB GPS Travel Logger GPS had many benefits including large data storage capacity and long battery life, durability, water-resistance, a light weight (21 grams) an unobtrusive design, and a relatively low cost (Vazquez-Prokopec et al., 2009). The GPS devices lasted the full week in most cases on one battery charge with a waypoint being obtained approximately every 3 minutes. The small rectangle design allowed ease of attachment to a cat harness with duct tape, and cats quickly became accustomed to their new device. Additionally, the devices could be easily pre-programmed on when to start, a large advantage as study participants did not need to be involved with the technology.

However, there were a few disadvantages of the GPS device. For two of the cats the last day of activity was not recorded, possibly because the battery ran out. I found no way to check how much longer the battery life was, even when plugged into the computer with the

software open. There was a trade-off between battery life and frequency of data collection (Vazquez-Prokopec et al., 2009), where recording every 3 minutes or longer to prolong battery could have resulted in loss of information where the participant stays at new locations for a brief time only. There were two outliers found, and GPS tracking had to be repeated for one cat. These inaccuracies may have been because the satellite could not get a good location fix due to tree, shrub, or house cover (Recio et al., 2011). There is a large risk of degradation of GPS signals because of poor signal deflection between the satellite and receiver device (Vazquez-Prokopec et al., 2009). Fortunately, there were no tall buildings near the Travis Wetland, but often cats were inside or under trees, and the device location could be off by 5-10 m or more (Vazquez-Prokopec et al., 2009). Some cats were not very compatible with the GPS. One GPS came off the harness and could not be found and three came back with bite marks in the duct tape. One cat had removed the duct tape layer, chewed through the gel casing, and damaged the GPS itself. Additionally, the behaviour of one cat was affected, where she had trouble wearing the GPS and harness because she could not easily get in or out through her cat door and had to be let out by her owners. Despite the few problems, the benefits of using the Mobile Action i-gotU USB GPS Travel Logger outweighed them.

Home Range Areas of Domestic Cats

Home range area estimates were similar to those of Morgan (2002). In my study they ranged between 1.34 and 9.69 ha and in Morgan (2002) they were between 0.1 and 10.1 ha. Morgan (2002) used 100% MCPs and the average home range area for 21 cats was 2.82 ha (median 1.8 ha). For the 14 cats in my study the 100% MCP average was 4.09 ha (median 3.54 ha). There were between 725 and 3049 GPS fixes in my study compared with between 47 and 102 radio fixes recorded for each cat by Morgan (2002). Using GPS compared with radio trackers provides more data which can help provide more detailed home range estimates, perhaps explaining why I had no home ranges as small as Morgan (2002). There were 3/14 (21%) cats in my study with home ranges larger than 5 ha. Morgan (2002) had only 3/21 (14%) cats with home ranges larger than 5 ha but her home ranges may be an underestimate due to her small number of fixes. Therefore, only a small proportion of domestic cats have large home range areas.

With increasing cat density, the movement of cats decreases (Liberg & Sandell, 1988). Urban areas have higher cat density, so movements are expected to be reduced compared with cats living in rural areas. Not straying too far from home can help them reduce confrontations with other cats (Bradshaw, 1992). Domestic cats spend a lot of time at home, which my 95% MCPs confirm. Barratt (1995a) found similar results for domestic cats in Australia. Along with avoiding confrontations, the cats are close to their primary food source and owners, and they can still hunt near their property. Morgan (2002) found that many cat owners reported that invertebrates and skinks were caught by cats on their property.

Over half of the cats (9/14) reached the wetland periphery. 100% of the cats with households right next to the wetland went to at least the walkways, whereas only half of the cats further from the wetland reached the periphery. Morgan (2002) suggested that the majority of cats using the Travis Wetland were probably from periphery housing, but it seems some reach the wetland from further out. Cats have been seen to swim or jump across drains, ditches, and the surrounding wetland moat, which allows them access to bird nestlings (Morgan, 2002). A high number of rodents, mostly mice, were found on the wetland periphery during past predator analysis of the area (Brom, 2000). Morgan (2002) observed cats stalking pukeko, mice, and skinks near the walking tracks around the periphery. The cats sighted by me and by Morgan (2002) were nearly all around the Wetland periphery. During skink trapping in February (chapter 5), I spent half of my time in the centre of the wetland (half the traps were in the centre and half around the periphery) yet only one cat was

observed near the centre compared with around 15 observed around the periphery near the walkways. Nesting birds and skinks that may be in the central parts of the wetland are therefore probably less exposed to predation by cats and other predators.

Home range areas of the cats in my study overlapped with some other home ranges although mostly by cats in the same household (two lots of cats). In both cases there was a male and a female living together, and the male had a much larger home range than the female cat. There have been observations that male and female home ranges tend to overlap extensively (Bradshaw, 1992; Liberg & Sandell, 1988). Domestic cats are usually less territorial (i.e. defensive of an area) than free-roaming cats as they have a reliable food source (Bradshaw, 1992; Fogel, 1991). They have been found to be more active between midnight and dawn compared with free-roaming cats being most active at dawn and dusk (Barratt, 1995; Bradshaw, 1992; Fogel, 1991; Izawa et al., 1982; Jones & Coman, 1981; Morgan, 2002). Domestic cats with their reliable food source are far less active than free-roaming cats which must hunt to survive (Barratt, 1995; Bradshaw, 1992; Fogel, 1991). Domestic cats spend a lot of time at home sleeping or interacting with owners (Fogel 1991; Morgan 2002), and the overlap of cats living at the same household reflect that. As shown by the 95% MCP, cats generally avoided each other's core house and garden areas, therefore research on domestic cats can reflect the behaviour of all cats even if there are some behavioural discrepancies.

Distance of the cat's household to the wetland had no effect on home range area. There was an effect of living near the wetland, as shown in the 100% MCP figures, the cats near the periphery had home ranges skewing towards the wetland which is consistent with Morgan (2002) and other studies. For example, Barratt (1995a) found cats living near a woodland habitat had skewed home ranges towards that as well. Cats were also affected by barrier such as busy roads (Barratt, 1995a), which were shown to influence the shape of the home range areas in my study. Only 4 out of the 14 cats appeared to have crossed the four main surrounding roads around the study area.

Cat age did not seem to affect home range area in my study. The ages of cats ranged between 1 and 14 years old. The cats that had a 100% MCP home range larger than 5 ha were 1, 2, and 9 years old and were all males. Other studies have found that younger cats have larger home ranges (Konecny, 1987; Mirmovitch, 1995; Morgan, 2002), but some studies reported that sub-adult males had smaller ranges than adult males (Fitzgerald & Karl, 1986; Gillies, 1998; Liberg, 1980). Territory (i.e. the defended area) may be a more important factor than age for determining home range area.

Many studies had shown cats have larger home ranges at night and only a few individuals were more active during the day (Alterio & Moller, 1997; Barratt, 1997; Langham & Porter, 1991; Page et al., 1992). However, Kikillus et al. (2017) found no significant difference in day and night time home ranges for 140 free roaming cats. When Kikillus et al. (2017) included all cats (31% cats locked in at night, 67% free roaming, 1% locked in during the day only, and 1% unknown) the average 95% MCP day time home range was 2.14 ha (median 0.7 ha) and the average night time home range was 2.14 ha (median 0.8 ha). For the 14 cats in my study (71% free roaming and 29% locked in a night) the average day time range was 0.65 ha (median 0.59 ha) and average night time home range was 1.06 ha (median 0.54 ha). In both cases the average is larger than the median as one or two cats have much larger home ranges compared with other cats, such as Tigger. Between the two studies both had similar ratios of free roaming and locked in at night cats, showing the Wellington cats (Kikillus, Woods, et al., 2017) had approximately double the home range sizes compared with the cats living around Travis Wetland.

The factor found to significantly influence cat movements in my study was sex for the 100% MCP, but the difference was not significant for the more robust 95% MCP. This is

similar to past results where males had larger home ranges but the differences were non-significant (Barratt, 1997; Fitzgerald & Karl, 1986; Gillies, 1998; Izawa et al., 1982; Langham & Porter, 1991; Meek, 1998b; Turner & Mertens, 1986). Morgan (2002) also found that male home ranges tended to be larger than female ranges, and at night, but not significantly. Similarly, male cats had larger home ranges at night than during the day for the 100% MCP. My results show that female domestic cats have non-significantly smaller home ranges at night and other studies have also found female movement to be smaller at night (Barratt, 1995; Morgan, 2002). Female cats may move further during the day when owners are not at home to provide food as there is often an increase in the diurnal activity of cats due to the provision of food by people (Turner & Meister, 1988). Similarly, free-roaming cats activity depends on the availability and density of prey (Konecny, 1987). Male home area size is usually limited by the distribution and density of female cats (Liberg & Sandell, 1988) but all cats in my study were desexed and desexed cats roam less than intact cats (Fogel, 1991).

There are numerous factors that affect the home range of cats to varying degrees, especially when near a natural reserve such as the Travis Wetland. Influences include dependence on owners for food, barriers, density of surrounding cat population, cat age and sex, seasonal changes in weather, prey availability and social interactions with owners and other cats (Barratt, 1995; Morgan, 2002). In Chapter 4 different management options as well as the results of my prey retrieval study are given, which can be tied into the findings of where cats may be hunting.

Chapter 4: Hunting Activity

4.1 Introduction

Domestic cats are carnivorous mammals and have been labelled as opportunistic hunters, preying on many species (Fitzgerald, 1988; Lepczyk et al., 2003; Liberg, 1984; Loyd et al., 2013). They are built for hunting with their excellent eyesight, especially at night, and hearing (Fogel, 1991). Cats negatively affect many other species and are known to have caused or contributed to some bird extinctions (Holdaway, 1989). There are indirect impacts on wildlife as well. Lower bird densities could reduce plant pollination, seed dispersal, density of dependent plant species, and increase insect numbers which may result in consequent plant damage (Şekercioğlu et al., 2004). Cats are carriers of disease such as *T. gondii*, ringworm, and hookworms which affect fitness and can result in mortality of other species (Howe et al., 2013; Proulx, 1988).

Cats are primarily nocturnal hunters as between dusk and dawn is when cats have greater hunting efficiency (Hernandez et al., 2018) as they have good low night vision (Wilkins, 2007). It was found that 83% of prey kills by stray cats occurred at night (Hernandez et al., 2018). Mammals especially are caught more often at night than during the day (Meek, 1998a). Even with a constant supply of food provided by owners, domestic cats will still hunt and kill prey, showing a behaviour independent of hunger (Leyhausen & Tonkin, 1979; Liberg, 1984). Without being hungry they may still hunt for play and practice for later hunts (Neville, 1992). Research with kittens showed that how effective that kitten will become at hunting when they are older depends on pretend predatory play and the observation of the mother's predatory behaviour including her bringing back live prey (Bradshaw, 1992). Cats have been shown to have a preference for small mammals such as rabbits and rodents, but if other prey such as lizards are readily available then they will switch to that (Fitzgerald, 1988; Gillies, 1998; King, 2005; Turner & Meister, 1988). Because of their wide diet, cats have threatened native birds in New Zealand, especially on islands, and they are partly responsible for the extinction of the Stephens Island wren (*Traversia lyalli*) and the decline of the New Zealand Dotterel (*Charadrius obscurus*) on Stewart Island (Dowding & Murphy, 1993; Galbreath & Brown, 2004). They have also been found to have negatively affected reptile populations (Towns & Daugherty, 1994).

Cats may negatively affect other wildlife, but the benefits of having cats around may outweigh the cons. Cats can assist in suppressing other predators. Removing cats may increase rat populations and rats have various negative effects which may be worse than any negative effects cats have (Fitzgerald, 1990). One study on cat diet on Christmas Island in the Indian Ocean found that cats helped to stabilise the island's population of rats, where if the cats were removed the nesting birds would be at serious risk of local extinction (Tidemann et al., 1994). In New Zealand, if feral cats were removed from the Orongorongo Valley in Wellington it would result in an increase of rat and mice numbers (Fitzgerald & Karl, 1979). Predation on rodents by feral cats keeps their populations in check. Rats carry diseases that can be transmitted to people and may be harder to keep under control compared with cats (Fitzgerald, 1990). Cats are usually vaccinated and undergo treatments to help with any potential disease. Cats are beneficial to humans by providing comfort, company, and amusement. Working out what values the public places on cats compared with wildlife could be incorporated in any decisions made about cat management (Fitzgerald, 1990).

Prey brought home by domestic cats is usually less than their actual catch rate and significantly less than what feral cats catch (Barratt, 1998; Churcher & Lawton, 1987; Fitzgerald, 1988; Gillies, 1998; Liberg, 1984). A recent study has shown that all past prey

retrieval studies may be large underestimates of actual prey caught by domestic cats. The study was carried out in south eastern USA using Kittercam video cameras to work out the proportion of hunters (Hernandez et al., 2018). Of the 29 cats, 83% showed hunting behaviour and 75% captured prey where the most common type was invertebrates and then amphibians and reptiles. Very few mammals were brought home, the opposite of what was expected, a result that may have reflected what prey was available to the cats at the time. For domestic cats, prey brought home may not reflect actual hunting behaviour as smaller prey may be eaten or killed where it was caught, and not brought home (Lloyd et al., 2013). Only 23% of the prey items were brought home, 49% were left at the capture site, and 28% were consumed by the cats before returning home (Lloyd et al., 2013). One study suggested inaccurate prey retrieval information may be caused by small prey being consumed quickly and not detected by household owners, prey remains of cats being scavenged by possums, dogs, and other predators, and prey brought home not being discovered (George, 1974). George (1974) found that three domestic cats living on a farm in the USA only brought home around half of the prey they caught. Therefore, there may be only 23-50% of prey brought home by domestic cats.

Studies of Domestic Cats in New Zealand

Five studies were found that carried out a prey retrieval study of domestic cats in New Zealand (Morgan (2002), Gillies (1998), Wood et al. (2016), van Heezik et al. (2010), and Flux (2007).

Morgan (2002) had 88 cats bring home 981 prey items over one year at the Travis Wetland, Christchurch during 2000. There were 21 native birds retrieved and the most common was silvereye followed by fantails, welcome swallows, and then kingfisher. Gillies (1998) carried out a study at two different locations in Auckland, Oratia and Browns Bay from January 1995 to January 1996. Oratia is surrounded by native forest reserves and Browns Bay is a fully urbanised location. In Oratia, 34 cats were involved in the study and brought home 734 prey items. In Browns Bay, 46 cats brought home 940 prey items. Wood et al. (2016) carried out a study on Stewart Island that lasted 6 months between February and July 2005. The study area was mostly residential, however the island itself is 85% National Park land. Only 11 cats participated, and four of them brought home 27 prey items. Three different residential types were defined in a yearlong Dunedin study as they were home to different bird communities, and differed in size of lawn and garden (van Heezik et al., 2010). Participation from 144 cats resulted in a total of 1887 prey items brought home. The 306 native birds that were caught consisted of silvereyes, fantails, tui, bellbirds and kereru. Compared with the other studies, the Dunedin cats were having a larger effect on native birds, and on birds in general. One cat was monitored for 17 years in Lower Hutt, Wellington (Flux, 2007). The study area was in the hills above Lower Hutt, and the cat had access to grassland and a mature forest. The cat brought home 558 prey items. The other mammals were rabbits, hares, and weasels. The 54 native birds brought home consisted of silvereyes, fantails, warblers, kingfisher, and shining cuckoo. Over the years there was no apparent change of bird or reptile abundance, but the cat kept the rabbit population controlled. When the cat was around 8-9 years old the frequency of prey retrieval decreased.

Studies of Domestic Cats Internationally

A total of 12 international studies were found that carried out a prey retrieval study of domestic cats. Two studies were Australian (Barratt, 1998; Meek, 1998a) and the rest were European (Baker et al., 2008; Borkenhagen, 1978; Carss, 1995; Churcher & Lawton, 1987; Kauhala et al., 2015; Krauze-Gryz et al., 2017; Krauze-Gryz et al., 2012; Thomas et al., 2012; Tschanz et al., 2011; Woods et al., 2003).

Barratt's (1998) study took place in Canberra, Australia. There were 138 cats that brought home 1961 prey items over one year. Meek's (1998) study took place in Booderee National Park, Jervis Bay, Australia. There were seven cats over six households that brought home 35 prey items were brought home during a one year period.

A study was carried out in Bristol, UK, with data being collected from various sites within the city to cover a range of different bird densities (Baker et al., 2008). The study was from December 2002 to August 2004. There were 275 cats from 186 households that brought home 495 prey items over the year. One study took place in Great Britain (Woods et al., 2003). There were 986 cats that participated, and they brought home 14370 prey items between April and August 1997. Another study took place in Finstersee, Switzerland (Tschanz et al., 2011). The area was a rural village surrounded by farmland and forests. There were 32 cats from 15 households that participated in a 48 day long study. They brought home a total of 142 prey items. One study was carried out in Finland between July and November 2009 and between March and December 2010 (Kauhala et al., 2015). The study area was the city of Turku, and there were urban and rural households involved. A total of 66 cats from 42 households participated over an average of 5.8 months and they brought home 1624 prey items. Krauze-Gryz et al. (2012) carried out a study in Poland. There were 34 cats from 16 households that participated. They carried out another study in central Poland (Krauze-Gryz et al., 2017). An average of 46.8 cats participated over 16 rural and 10 urban households for one year and they brought home a total of 1348 prey items. Thomas et al. (2012) carried out a study in Reading, UK. There were 348 cats from 211 households that participated for 5.4 seasons on average and brought home 988 prey items. Churcher & Lawton (1987) carried out a study in Felmersham, UK. There were 70 cats that participated over one year and brought home 1090 prey items. Woodmice, sparrows, and bank voles were the most important prey of the cats. In one study in Scotland, only two cats participated (Carss, 1995). One male from Kincardineshire and one female from Argyll. The male participated for two years between June 1991 and May 1993 and brought home a total of 228 prey. Over a year he brought home 114 prey items. The female participated for 15 months between December 1983 and February 1985 and brought home 206 items. Over one year she brought home 165 prey items. Finally there was a study that took place in Germany (Borkenhagen, 1978). There were 54 cats that participated, and they brought home a total of 309 prey items.

To compare with results from eighteen years ago and with the various other studies, methods from Morgan (2002) were replicated. To estimate the loss of wildlife in the area because of the cats, the households recorded prey items brought home. My study aimed to see how things have changed over time, as there are now newly developed houses, fewer cats (Chapter 2), and an increased understanding of cat management. I wanted to find out what the proportion of different prey items is next to the Travis Wetland area. I aimed to find out if there was relatively fewer prey items and a lower number of prey per cat per year compared with Morgan (2002).

4.2 Methods

Methods for contacting houses near Travis Wetland were described in Chapter 2. For the households that indicated they had one or more cats during the door knock or letterbox responses, they were asked to participate in a prey retrieval study. Participants in the prey retrieval study were asked to store prey items in a polyethylene zip lock bag and store it in the freezer until they could be picked up, or to take a photo and sent it in an email so that the identification of the species could be confirmed and then they could throw the prey away. A prey retrieval sheet (see Appendix) was provided so that information about the prey could be

noted down, such as where the prey was found, and where. At the end of the first month, participants were emailed to remind them about the study and to ask if anything had been caught yet. After three months, the households were visited to encourage participation and to retrieve filled in prey record sheets and provide new ones. Prey items were identified down to the species level when possible. The study started between 13 March and 7 April 2018. It finished between 15 September and 6 October, depending on when the household initially started. Each household participated for 6 months.

Information from the completed survey about the cat's characteristics (Chapter 2) was used to compare hunting activity between different cats using Mann-Whitney U tests (U) and Spearman's rank correlation (r_s). Information such as distance to wetland periphery and home range (Chapter 3) was analysed using Pearson correlation. Prey per cat per year and prey composition was compared with other studies in New Zealand, including Morgan (2002) using Pearson's Chi-squared tests (χ^2).

Additionally, a literature review of domestic cat prey retrieval was carried out. The Scopus database was used to search for relevant studies on cat hunting activity. The following search terms were used in various combinations: prey, retrieval, cat, predation, diet, *Felis catus*, hunting, domestic, house, and household. Once a relevant study was found, the references it used that referred to cats were searched to see if they were specifically about prey retrieval by domestic cats. Two different categories were used to describe the results, these were domestic cats in New Zealand and domestic cats internationally. Comparisons were made between New Zealand studies, including mine, with overseas studies in Australia and Europe.

4.3 Results

Initially 32 households with 54 cats agreed to participate in the prey retrieval study. Three households were subsequently excluded as they moved out of the area during the 6 months. Another three households changed their mind about participating and withdrew from the study. In the end, 26 households with 41 cats participated in the prey retrieval study and I had confirmed number of prey items from those houses (Table 4.1).

Analysing vertebrate prey recordings can be difficult. Insect prey is sometimes excluded from cat prey retrieval studies as the owners may not be recording the data consistently (Tschanz et al., 2011). Two of the households mentioned that their cats played with or killed worms and moths, but these were not recorded during the study. One cat caught one monarch butterfly (*Danaus plexippus*) but this was not included in my study due to the inconsistency of households recording invertebrates.

After confirming the participation of the 26 households, there were variations on the duration of some participating cats. The only cat from one household (ID1) died in early April, but it had caught a mouse during March and so was included in the study, and therefore participated for one month. One cat from a household of three older cats (ID2, 3, or 4) died during the study but the prey caught was included in the study. The owner was not sure which cat caught the prey. The only cat from one household (ID65) ran away during the study but it had brought home two prey items before that and was included in the study. For the two latter households, the exact dates were not provided for when those cats stopped participating and so an assumption of 3 months was given. For two household there were three cats (ID18,19,20/ID59,60,61) but two were indoor only (ID20/ID61) and therefore were excluded from further analysis. I was able to include the other four cats in these households.

Table 4.1. Cat prey retrieval participants from each household and the prey they brought home. Under the “Cats” heading is the maximum potential number of cats that could have participated in bringing the prey home from each household.

Cat ID	Cats	Total Prey	Rodent	Exotic Bird	Native Bird	Cat-years	Prey per cat-year
1	1	1	1	0	0	0.08	12.00
2, 3, 4	1	1	1	0	0	1.25	0.80
5, 6	0	0	0	0	0	1.00	0.00
7	0	0	0	0	0	0.50	0.00
11	1	19	17	0	2	0.50	38.00
13, 14	1	1	0	0	1	1.00	1.00
15	0	0	0	0	0	0.50	0.00
17	1	1	1	0	0	0.50	2.00
18, 19	1	1	0	1	0	1.00	1.00
25	0	0	0	0	0	0.50	0.00
28, 29	2	2	1	1	0	1.00	2.00
30	1	1	0	1	0	0.50	2.00
31	1	1	0	1	0	0.50	2.00
38	0	0	0	0	0	0.50	0.00
39, 40	1	1	1	0	0	1.00	1.00
41, 42	0	0	0	0	0	1.00	0.00
43	1	1	0	1	0	0.50	2.00
46, 47, 48	0	0	0	0	0	1.00	0.00
51	1	2	2	0	0	0.50	4.00
57	0	0	0	0	0	0.50	0.00
58	0	0	0	0	0	0.50	0.00
59, 60	2	3	0	1	2	1.00	3.00
62, 63, 64	0	0	0	0	0	1.50	0.00
65	1	2	2	0	0	0.25	8.00
70, 71, 72	3	4	0	4	0	1.50	2.67
74	1	1	0	1	0	0.50	2.00
Totals	20	42	26	11	5		3.21

Total Prey

Over the 6 month study period between March and October, a total of 42 prey items were brought home (Table 4.2). The prey items were brought home by between 17 and 20 out of 41 cats (41.5 – 48.8%) and 16/26 (61.5%) households. ID59 (Mika) caught one exotic bird and ID60 (Lilly) caught two native birds, whereas at households with ID28,29 and ID70,71,72 cats it was uncertain which cat brought home which prey item. For 42 prey items brought home by 41 cats over the study period, that is an average of 3.21 (± 1.49) prey items per cat per year. The back transformed mean of the log-transformed prey per cat-year was 1.33 (SEM 0.94 – 1.79). For an estimated 429 cats in the area (Chapter 2) using the average of 3.21 per cat per year, that is 1377 prey items brought home in a year. However, one cat (ID11, Max) brought home nearly half of the prey (19/42, 45.24%) and was labelled a superpredator. Which cat brought home each specific item could be identified for 31 of the

cats, of which 13 brought home at least one prey item (42%), therefore 58% of the 31 cats did not bring home any prey.

Prey Composition

The rodents brought home were rats and mice. The exotic birds brought home were thrush, domestic rock pigeon, blackbird, and sparrows. All native birds brought home were silvereyes. There were also unidentified bird feathers recorded. Max brought home 17 baby rats and two silvereyes. The IUCN status retrieved from the IUCN Red List Website indicated all species are “Least Concern”. The composition was 62% rodents, 26% exotic birds, and 12% native birds (Figure 4.1)

Table 4.2. Prey brought home by domestic cats around the Travis Wetland. Only silvereyes are a native species.

Common name	Scientific name	Number	Percentage (%)
Rodent		26	61.90
House mouse	<i>Mus musculus</i>	7	16.67
Ship rat	<i>Rattus rattus</i>	19	45.24
Bird		16	38.10
Blackbird	<i>Turdus merula</i>	1	2.38
Rock pigeon	<i>Columba livia</i>	2	4.76
Silvereye	<i>Zosterops lateralis</i>	5	11.90
Sparrow	<i>Passer domesticus</i>	6	14.29
Song thrush	<i>Turdus philomelos</i>	1	2.38
Unidentified bird		1	2.38
Total		42	

Effect of Cat Characteristics

There were 26 households with 41 cats that participated. There were 34 out of 42 prey items that could be paired to 31 distinct cats. The other 10 cats were at three households with three cats and one with two cats. For these households either the information of what cat brought home what prey was not provided or was unknown by the owner.

Where prey could be assigned to a specific cat, there were 15 (48%) males and 16 (52%) females and sex did not have a significant effect on prey brought home ($U_{15,16} = 116.5$, $p = 0.89$). Age was provided for 30 of the cats, with an average age of 8 (to the nearest year) and range from 1 to 18 years old. The age of the cat did not have a significant effect on prey brought home ($r_s = -0.008$, $df = 28$, $p = 0.97$). There were 24 mixed breed cats (moggies, domestic shorthair and longhair, and a ragdoll cross), 4 purebreds (Abyssinian, Exotic shorthair, and two British shorthair), and two unknown breeds. The breed of the cat did not have a significant effect on prey brought home ($U_{24,4} = 74$, $p = 0.09$). However, none of the purebred cats brought home prey. There were 24 (75%) free roaming cats and 7 (22%) locked in at night. The number of prey items brought home by cats did not differ significantly between the two types of movement restrictions ($U_{24,7} = 102.5$, $p = 0.34$). There were 14 cats that wore a collar and 17 that did not. Of the 14 cats that wore a collar, 7 also wore a bell. There was no significant difference between cats wearing a collar with a bell and cats without a bell in whether they caught prey or not ($\chi^2 = 0.71$, $df = 1$, $p = 0.42$) and the number of prey items brought home did not significantly differ ($U_{24,7} = 102.5$, $p = 0.34$).

For the 31 cats where prey was known for each cat, the distance of the cat's household to the wetland periphery did not have a significant effect on number of prey items brought home ($r_s = -0.19$, $df = 29$, $p = 0.32$). There were 13 out of 14 cats that participated in both GPS and prey retrieval studies. The home range 100% area for these cats did not have a significant effect on prey brought home ($r_s = 0.16$, $df = 11$, $p = 0.60$) and nor did the 95% home range area ($r_s = 0.31$, $df = 11$, $p = 0.31$) or 50% area ($r_s = 0.29$, $df = 11$, $p = 0.33$).

Domestic Cats in New Zealand

Comparing all studies prey per cat per year shows that different studies have different numbers of prey caught than what was relatively expected ($\chi^2 = 125.97$, $df = 5$, $p < 0.001$). Table 4.3 shows the percentages of prey caught for each New Zealand study. Morgan (2002), Gillies (1998), and van Heezik et al. (2010) studies had no significant difference in prey per cat per year ($\chi^2 = 2.47$, $df = 2$, $p = 0.292$). When Wood et al. (2016) was included, there was a significant result ($\chi^2 = 15.15$, $df = 3$, $p = 0.002$) showing that for that study cats brought home relatively less prey than what was expected. There was significantly fewer prey brought home per cat per year in my study compared with Morgan (2002) ($\chi^2 = 47.63$, $df = 1$, $p < 0.001$) and significantly more prey brought home for Flux (2007) than what was relatively expected.

The prey composition from my study was significantly different from the Morgan (2002) study ($\chi^2 = 28.37$, $df = 5$, $p < 0.001$) both shown in Figure 4.1. In my study and New Zealand studies combined there were not more rodents brought home than birds but there were more rodents brought home than native birds (Figure 4.1, 4.2). Additionally, there was no large difference between number of birds and reptiles brought home.

Table 4.3. Prey retrieval studies for domestic cats in New Zealand. Numbers given as percentages. Other is amphibians and fish. Excluding invertebrates and unidentified.

Author (s)	Date	Location	Rodents	Other Mammals	Native birds	Exotic birds	Reptiles	Other	Prey per cat per year
Morgan	2002	Travis Wetland, Christchurch	50	0	3	23	23	1	8.64
Gillies	1998	Oratia, Auckland	72	1	4	10	12	0	19.82
		Browns Bay, Auckland	16	0	7	54	22	0	4.52
Wood et al.	2016	Stewart Island	67	0	11	22	0	0	3.60
van Heezik et al.	2010	Dunedin	43	1	21	25	10	0	10.24
Flux	2007	Lower Hutt, Wellington	51	7	10	30	2	0	32.82

Domestic Cats Internationally

Table 4.4 shows the percentages of prey brought home by domestic cats internationally. The average percentage of prey brought home by the international studies compared with the New Zealand studies, which includes my own, is shown in Figure 4.2 below.

All studies in New Zealand combined, Australia combined, and Europe combined were significantly different from one another, showing unique differences in prey composition of rodents, other mammals, birds, and reptiles ($\chi^2 = 2081.46$, $df = 6$, $p < 0.001$). For the international studies domestic cats brought home more rodents than birds. This supports the view that cats prefer catching small mammals. There was no large difference in number of mammals brought home and birds. Reptiles were less commonly brought home in international studies compared with New Zealand.

Table 4.4. International studies on prey retrieval of domestic cats. Numbers given as percentages. Other is amphibians and fish. Excluding invertebrates and unidentified.

Author (s)	Date	Location	Rodents	Other Mammals	Birds	Reptiles	Other	Prey per cat per year
Barratt	1998	Canberra, Australia	63	2	27	7	1	14.20
Meek	1998	Jervis Bay, Australia	29	46	20	6	0	5.00
Baker et al.	2008	Bristol, UK	66	1	24	5	4	1.79
Woods et al.	2003	Great Britain	45	25	24	1	4	34.10
Tschanz et al.	2011	Finstersee, Switzerland	83	5	12	0	0	25.44
Kauhala et al.	2015	Finland	72	7	18	3	0	46.65
Krauze-Gryz et al.	2012	Poland	65	11	14	8	2	31.30
Krauze-Gryz et al.	2017	Poland	62	11	16	10	2	28.80
Thomas et al.	2012	Reading, UK	52	14	31	0	3	2.10
Churcher & Lawton	1987	Felmersham, UK	38	27	36	0	0	14.00
Carss	1995	Kincardineshire, Scotland	54	23	23	0	0	114.00
		Argyll, Scotland	71	23	5	0	0	164.80
Borkenhagen	1978	Germany	48	29	22	0	0	-

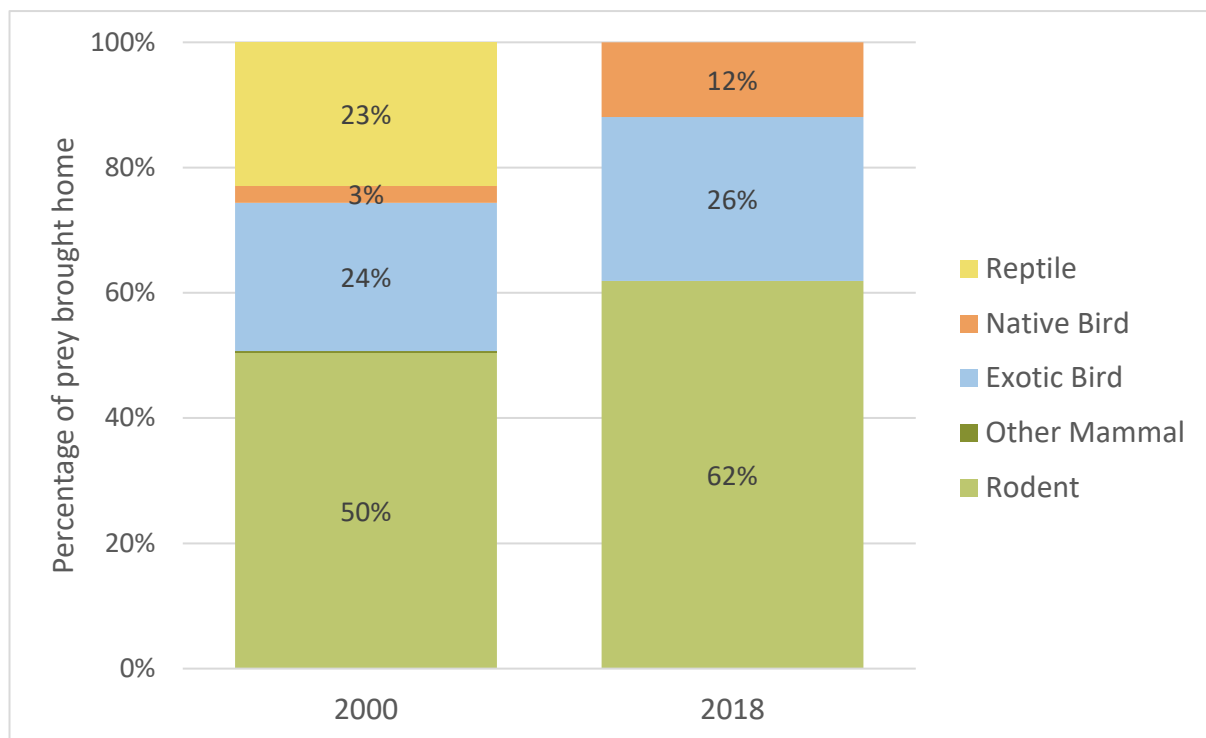


Figure 4.1. The percentage of prey brought home by domestic cats living around the Travis Wetland in 2000 (Morgan, 2002) compared with my study in 2018.

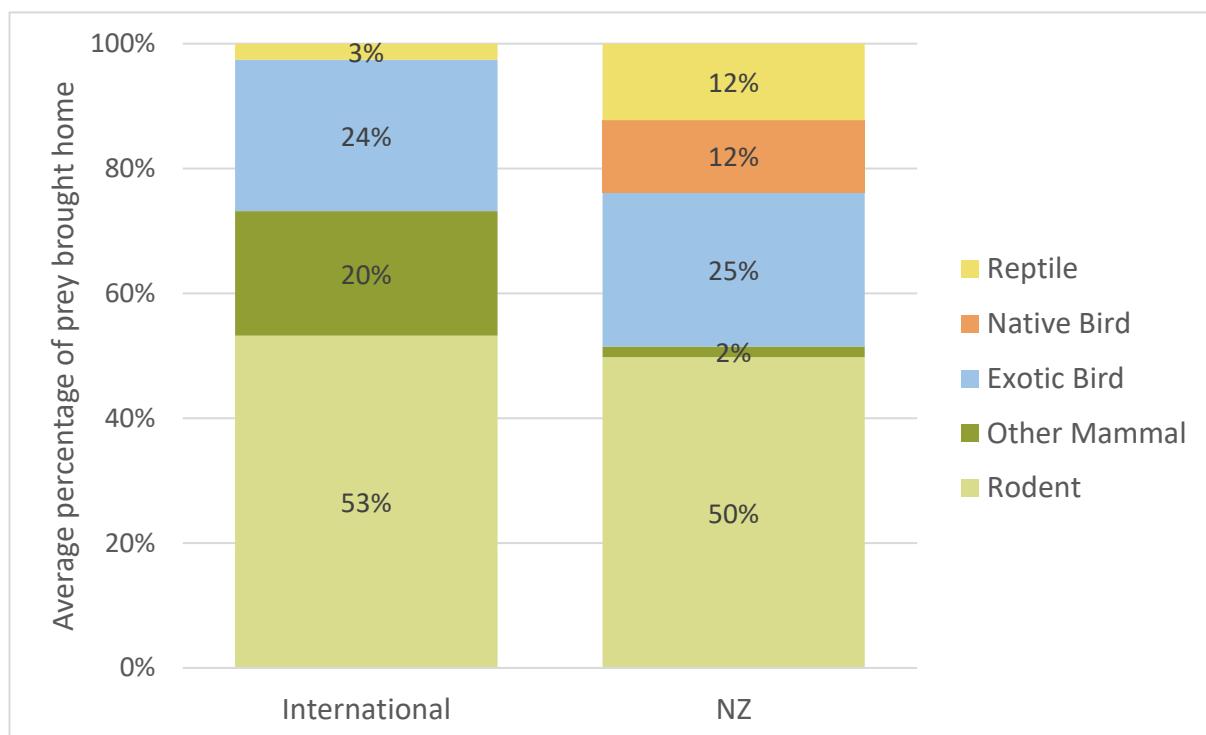


Figure 4.2. The average percentage of prey brought home by domestic cats internationally and in New Zealand. International included Australian studies (Barratt, 1998; Meek, 1998a) and European studies (Baker et al., 2008; Borkenhagen, 1978; Carss, 1995; Churcher & Lawton, 1987; Kauhala et al., 2015; Krauze-Gryz et al., 2017; Krauze-Gryz et al., 2012; Thomas et al., 2012; Tschanz et al., 2011; Woods et al., 2003). New Zealand studies include my study as well as five others (Morgan (2002), Gillies (1998), Wood et al. (2016), van Heezik et al. (2010), and Flux (2007)).

4.4 Discussion

Prey Number and Composition

An estimated 429 cats in the Travis Wetland area (Chapter 2) means around 1377 prey items would be brought home per year compared with Morgan's (2000) study with 494 cats for over 5400 prey items brought home per year. Most of the prey caught by domestic cats in the Travis Wetland area were rats. During the Morgan (2002) study, the main prey item was recorded as house mice which consisted of 97% of the rodents. During my study, mice were also brought home by cats, but my rats were all identified as either juvenile or adult ship rats whereas Morgan (2002) recorded all her rats as Norway rats. Some of the mice in Morgan (2002) may actually have been juvenile ship rats as they are visually similar. Some identification is done through just parts of an animal which is difficult. Gillies (1998) in comparison to Morgan (2002) and similar to my study found that juvenile rats were the most common prey of domestic cats that lived in Auckland, New Zealand. The studies so far have supported the idea that the main prey of cats is small mammals such as rodents. However, cats are opportunistic hunters and also prey on other prey such as birds and lizards (Fitzgerald, 1988; Morgan, 2002). For example, in my study one cat brought home a domestic rock pigeon, from the neighbour's property where they breed them. Krauze-Gryz et al. (2017) showed seasonal variation in prey composition of cats is relatively high in rural environments compared with stable prey composition in urban environments. Other than the lack of lizards brought home by cats in my study, percentages of prey between this study and Morgan (2002) are similar.

Across NZ, my study and Wood et al. (2016) showed lower than expected prey per cat per year, while Flux (2007) showed higher than expected numbers. Wood et al. (2016) explained that the low number of prey items could have been because the small sample of cats may have been biased towards non-hunters or that owners were not accurately observing or reporting prey retrieved. The unusually high number of prey items brought home by the single cat in Flux (2007) may be due to the cat being a superpredator, where the nearby rabbit population was kept in check by the one cat. The cat was born in the wild and fed on prey caught from the wild when it was a kitten (Flux, 2007), so the hunting behaviour was probably closer to a free-roaming cat, not a domestic cat.

There were significantly fewer prey brought home per cat per year in my study compared with Morgan (2002). This may be because of a change in prey abundance, change in cat catch rates, or a change in household reporting rates. Very similar methods to previous studies for interacting with households were used, so it is least likely to be because of reporting bias. There may be reporting bias across all studies, but it cannot be quantified. My study had the addition of increased contact via email compared with face to face, but this should not have affected numbers as at the end of the study all numbers of prey were confirmed in person if possible. The lack of prey brought home in general compared with Morgan (2002), may reflect the reduction of pests in the wild due to continued trapping by the Travis Wetland rangers and presence of cats in the area. In my study there was one superpredator, Max, but there would more superpredators in the area, so this sample of cats may be greatly underestimating catch rates in the area. Or catch rates may have actually decreased, with fewer cats and cats per household in the area. Morgan (2002) noted that more prey was retrieved by cats in the summer of 1999/2000 than 2000/2001. This may indicate gradually declining numbers of wildlife in the area. Morgan's study had a focus on seasonality of prey intake, but my study was only for 6 months, so comparisons may not be accurate.

One study had 60% of the cats involved not bring home any prey over the year of study (Baker et al., 2008). Baker et al. (2008) acknowledged how people may not want to participate if their cat does not bring much home thinking the info is not important, or they

may not want to participate to hide the fact their cat brings home lots of birds. Tschanz et al. (2011) had 34.4% of the cats not bring home any prey. My study had 58% of the cats not bring home prey so seems to be comparable to other studies. However, in these studies cats that do not bring home prey may still catch it and leave it outside or consume it in situ (Loyd et al., 2013).

Cats mainly brought home small mammals in all these studies and there were significantly more rodents than native birds. However, the KittyCam studies carried out by Loyd et al. (2013) in Georgia, USA showed that cats caught more lizards (36% of the prey caught), specifically Carolina anoles (*Anolis carolinensis*) compared with mammals (26% of prey caught). The video showed that 88% of reptiles and amphibians were not brought back to households so many prey retrieval studies are most likely underrepresenting them. During Morgan's (2002) study there was a large 18% of prey that consisted of lizards, but none were confirmed to be caught during my study. Chapter 5 covers the estimated skink abundance at the Travis Wetland, which is low, possibly explaining low prey retrieval of lizards.

Many studies have supported that cats are opportunistic predators and the prey they capture or bring home correlates with prey availability (Loyd et al., 2013). There was a higher proportion of birds caught in New Zealand than the combined international studies, which may reflect the relatively higher number of birds in New Zealand compared with overseas. The highest percentage of prey brought home being small mammals may reflect the large abundance of mammals in the area, but it also may be an underrepresentation of prey caught by cats which do not bring most of their prey home (George, 1974; Hernandez et al., 2018; Loyd et al., 2013). A more likely explanation for the high percentage of mammals being brought home is that cats are nocturnal hunters with good low light vision (Hernandez et al., 2018; Wilkins, 2007).

Effect of Cat Characteristics

The results from the prey retrieval study in my study could not be explained in part by the characteristics of the cats that took part. Sex, age, breed, and movement restrictions had no significant effect on prey retrieved by the cats. Whether the cat wore a collar with a bell or not also had no significant effect. Additionally, the distance of the cat's household to the wetland periphery and the 100% and 95% home range areas did not correlate with prey retrieval. Morgan (2002) had high correlations between cat age and the distance of the cat's home from the wetland periphery with hunting activity as well as cat movement. Similar to my study, sex and whether the cat had a bell or not had no effect on the rates of predation (Morgan, 2002).

Home Range Size and Prey Retrieval

There was no significant effect of home range size of the domestic cats (Chapter 3) on prey retrieved. Morgan (2002) found that cats with larger home ranges and movements into the wetland brought home more prey, showing they may be using the wetland to hunt. Yet during my study there was no relationship between home range area and prey retrieved. The prey availability around neighbourhood areas and the wetland periphery may have changed since the last study. Morgan (2002) had suggested the difference was explained by the greater diversity and abundance of prey items in the Travis Wetland compared with the surrounding urban area. In my study, the lack of relationship between home range area and prey retrieved may be because the cats did not go far into the wetland, only to the periphery edge, where available prey may not have been significantly different from prey in the suburbs.

Free-roaming Domestic Cats at Night

The majority of studies have a focus on seasonal trends, but some Australian studies looked specifically at the times prey was brought home (Barratt, 1995; Meek, 1998a). Meek (1998) found that mammals consisted of 75% of prey brought home and were all caught at night (households awoke to prey in the morning). Birds and reptiles were brought home during the day. In one study using the Kittercam video camera, 83% of all kills by cats occurred between dusk and dawn (Hernandez et al., 2018). Barratt (1995) suggests not to keep cats indoors at night unless predator control is increased for rodents and other mammals. This is because all amphibians and 62% of mammals were caught at night by free-roaming cats. During the day 70% of birds and 90% of reptiles were brought home where reptiles were more likely to be caught during the afternoon. In one study it was found that cats kept in at night caught significantly fewer mammals and significantly more lizards and amphibians, but not birds (Woods et al., 2003). In New Zealand, it is not a negative action for native wildlife when cats bring home mammals. In a survey carried out by Kikillus et al. (2017) there were 2 out of 209 cats that were confined during the day but let out at night, a rare situation. The other cats were either free-roaming or locked in at night.

The SPCA (The Society for the Prevention of Cruelty to Animals Incorporated) recommends keeping cats inside at night because it reduces cat fights, motor vehicle accidents, and is the time when they are most active hunting (<https://www.sPCA.nz/advice-and-welfare/article/creating-an-enriching-home-environment-for-your-cat?cat=pets&subcat=cats>, January 2019). But in New Zealand, where the mammals hunted at night are introduced pests, cats hunting at night may be advantageous to keep rodent numbers down. It has been suggested that if more households take part in intensive rat trapping, their populations would diminish, and in this case, appropriate cat ownership would involve any new cat owners keeping their cat indoors from the start (<https://www.stuff.co.nz/environment/81980660/cat-owners-have-a-role-in-a-predator-free-new-zealand>, January 2019). Cats also inflict indirect negative effects on rodents, as they are one of the definitive hosts of *T. gondii* and shed their oocysts which intermediate hosts ingest (Tompkins & Veltman, 2015). Rats infected with *T. gondii* have a decreased fear of anything new (neophobia) and increased activity, resulting in increases in their trappability (Tompkins & Veltman, 2015; Webster, 1994; Webster et al., 1994). Before management or removal of cats from an area, *T. gondii* could be purposely spread through the rodent population (Tompkins & Veltman, 2015).

Reducing Cat Predation

There are many products on the market now that can help to reduce cat hunting behaviour. In New Zealand however, reducing predation on introduced predators such as rodents may be detrimental to other wildlife such as birds. Products that can help reduce bird, lizard, and native insect kills, but not mammals, would be perfect to use for domestic cats. BirdsBeSafe® collars (<https://www.birdsbesafe.com/>, November 2018) and the CatBib™ (<https://www.catbib.com.au/>, November 2018) have been shown to reduce bird predation (Calver et al., 2007; Gillies & Cutler, 2001; Willson et al., 2015). BirdsBeSafe collars were found to reduce the number of birds brought home by cats, where cats without the collar attachment caught 19 times more birds in spring and 3.4 times more birds in autumn (Willson et al., 2015). In a study testing how well the CatBib works, over 80% of cats stopped bringing home birds (Calver et al., 2007). There are many positive reviews about the CatBib (<https://catgoods.com/category/catbib-customer-testimonials/>, November 2018). Two out of 62 cats had paws caught in their collars, with one resulting in a trip to the vet, so instructions would have to be carefully followed for the safety of the cat (Calver et al., 2007). Cats wearing the CatBib were less likely to get into cat fights but not significantly (Calver et al., 2007) and

cats wearing either the CatBib or BirdsBeSafe collar did not have an effect on home range size (Calver et al., 2007; Hall et al., 2016).

Using a collar with a bell attached is a method that is widely debated if it has an impact or not on hunting success (Gordon et al., 2010). In my study and Morgan (2002) there was no significant difference in cats bringing home prey when wearing a bell or not. In another study, with the collar on, bird predation was reduced by 50% and rodent predation was reduced by 61% (Gordon et al., 2010). Rats specifically, lizards, and insect catch rates were not significantly reduced. The collars may have been effective to reduce bird predation somewhat, but in New Zealand the reduction of predation on small mammals is detrimental to wildlife. It was noted that a 50% decrease in predation of birds may not be significant to ensure their survival anyway (Gordon et al., 2010).

The Liberator® is another approach to reducing cats hunting behaviour. It is an electronic audio-visual alarm device that is placed on an existing cat collar (Gillies & Cutler, 2001). It activates a flashing red light and piercing beep sound when the cat leaps towards prey and it is claimed to reduce predation on adult birds (Gillies & Cutler, 2001). Cats wearing the collars brought home fewer birds, mice and reptiles, but only invertebrate numbers were significantly fewer. There are superpredator cats that catch a larger proportion of prey than other cats. Gillies (2001) suggested that future studies carried out should equally stratify those advanced hunters into each treatment group. The Liberator has received negative feedback online which should be considered before using the product (https://www.petplanet.co.uk/product_review.asp?dept_id=147&pf_id=1252, November 2018). The device activates occasionally when the cat is not moving and can also prevent the cat from playing with toys. Using any sort of collar will at least increase awareness of prey that your cat is bringing home.

In New Zealand where we want cats to catch rodents and not birds, then using the brightly coloured BirdsBeSafe collar that visually warns birds away and comes with a breakaway collar insert may be the best option for free-roaming cats.

Studies on the CatBib and Birdsbesafe collar have been carried out in the USA and Australia, but not yet in New Zealand. Tests should be carried out in New Zealand to see the how successful those products are at reducing cat predation on birds. Also, in New Zealand, research could be carried out using the Kittercam product to estimate true catch rates on domestic cats.

More studies of prey brought home, with the true catch rates in mind, could be carried out in fully urban areas and fully natural areas, such as suburb areas with no natural reserves nearby and areas in the Port Hills respectively. More studies to represent different parts of urban cities are important to help draw a larger picture of what the impacts cats may be having on wildlife are.

In New Zealand, until management programmes can target all predators, especially rodents in urban areas, domestic cats could stay out at night to help keep other predators in check as they prefer to prey on mammals, not birds. Additionally, keeping cats indoors during the day could reduce the number of birds and lizards brought home (although cats did not bring home skinks in this study). Ideally, there would be no predators in the wild in New Zealand and the native birds and skinks would not be threatened with extinction, and domestic cats would be kept indoors. Confinement of the cat provides protection from cat fights, traffic accidents, and other threats (Metsers et al., 2010). As long as the cat does not experience boredom or stress, stays active, and does not spray urine or scratch, keeping all cats indoors in the future would not be problematic (Rochlitz, 2005).

Chapter 5: Skink Abundance

5.1 Introduction

Many studies have estimated the abundance of skinks within New Zealand (Enge, 2001; Freeman, 1997; Freeman & Freeman, 1996; Gebauer, 2009; Lettink & Cree, 2007; Towns & Elliott, 1996; van Heezik & Ludwig, 2012). However, only a handful have combined a predation study with the abundance study (Dumont, 2015; Jones & Bell, 2013; Norbury, 2001; Norbury et al., 2009; Wilson et al., 2007; Wilson et al., 2017). These studies are important to help understand what intensity level of predator control is required for the conservation of prey species.

The extinction of lizard populations and the main threat to their abundance is usually the result of direct predation (Case & Bolger, 1991; Wilson et al., 2017). In New Zealand the largest diversity of lizards is confined to islands, primarily due to new predators brought in from overseas on the mainland (Holdaway, 1989; Towns & Daugherty, 1994; Towns & Elliott, 1996). There are now 11 introduced mammalian predators that slowly arrived with the arrival of humans (King, 2005). Rodents, mustelids, and cats can greatly reduce lizard populations (Towns & Daugherty, 1994). Coevolution of species can act to reduce the intensity of predator-prey interactions, but New Zealand lizards may not have had a chance to adapt to the relatively recently introduced predators (Case & Bolger, 1991). One adaptation of some lizards is to drop their tail which gives them a chance to run away, an anti-predator behaviour called caudal autotomy (Cromie & Chapple, 2012; Patterson, 1985). During summer months skinks build up and store most of their fat reserves in their tails and in their abdominal fat bodies and use those reserves over winter (Patterson, 1985). Losing a tail may increase immediate survival but it has long term negative effects such as inhibition of locomotor performance, habitat use and activity alterations, the loss of fat reserves and increased susceptibility to any following predation attempts (Bateman & Fleming, 2009; Cromie & Chapple, 2012; Patterson, 1985).

Various studies have looked at what impact predators may be having on skink abundance in New Zealand. Wilson et al. (2007) found there were more skinks present in retreats within a mammal-resistant fence compared with outside near Macraes Flat, South Island. In a further study, they found there were population increases in all lizard study species, including the Southern grass skink (*Oligosoma* aff. *polychroma* clade 5) where mammalian predators were suppressed (Wilson et al., 2017). However, they did not have baseline numbers so differences may have arisen due to suitability of different site habitats (Wilson et al., 2017). In another study near Macraes Flat juvenile McCann's skinks (*O. maccanni*) declined in numbers with increasing hedgehog density (Jones & Bell, 2013). Domestic and feral cats are predators that can be huge threats to lizard populations. Rock iguanas (*Cyclura carinata*) on Caicos Islands were seriously impacted by predation by domestic dogs and cats (Iverson, 1978). Giant lizards (*Gallotia* spp.) on the Canary Islands have greatly declined mainly because of predation by feral cats (Nogales et al., 2006). In Travis Wetland, Christchurch, cats have been found to prey heavily on the local Southern grass skink, where 18% of what domestic cats brought home were those lizards (Morgan, 2002). Along with the various mammalian predators that skinks hide or defend themselves from, avian predators are also a problem (Jones & Bell, 2013). In a study on Miyake-Jima, a Japanese island, it was found that thrush (*Trudus celanops*) were size-limited predators of the local lizard *Eumeces okadae*, selecting lizards small than 48 mm snout-vent length (Hasegawa, 1990). In the Travis Wetland, the study site of this research, there are song thrush (*Turdus philomelos*), kingfisher (*Todiramphus sanctus*), blackbird (*Turdus merula*), kererū, magpies (*Gymnorhina tibicen*),

rock pigeon, and starlings (*Sturnus vulgaris*) that may all prey on local lizards. Where abundance of skinks is high, there is not a significant effect of predator impact, but small populations are at risk of becoming locally extinct (Jones & Bell, 2013; Norbury, 2001).

Not only does direct predation influence lizard survival, but indirect effects can also product negative outcomes. Dumont (2015) found that skinks had worse body condition when mammalian predators were present compared with no predators in the South Island. Therefore, direct predation may not be the only cause of decline in lizard species, but also indirect stresses which can affect fitness of the individual and lead to reduced reproductive efforts (Dumont, 2015). Some mammalian predators, especially rodents, may compete with lizards for food such as invertebrates and fruits (Dumont, 2015). This competition may reduce lizard survival as they would have to expend more energy on foraging.

Diversity

The most recent estimate for number of reptile species in New Zealand is 108 (Bell, 2014). Many of these are new species described, as in the 1980's only 34 reptile species were recognised and in 2009 there were 56 recognised species (Tennyson, 2010). The newly recognised species are mostly due to taxonomic splitting using allozyme data and morphological analysis, and not the discovery of new reptiles (Daugherty et al., 1994; Tennyson, 2010). Lizards in New Zealand, consisting of geckos and skinks, are relatively more diverse compared to lizards in other temperate environments such as Australia (Daugherty et al., 1994; Towns & Daugherty, 1994). There is an estimated 41 gecko species and 57 skink species (Bell, 2014). Of the skinks, 56 are in the genus *Oligosoma* (formerly *Leiopisma*) and one is an introduced species from the genus *Lampropholis* (Bell, 2014; Patterson & Daugherty, 1995). This is also a more recent estimate, as the past estimate was 28 skink species where 22 were in the genus *Oligosoma* (Gebauer, 2009). For vertebrates in New Zealand, lizard diversity comes second only to birds with an estimated 374 species (Heather & Robertson, 2015).

The species richness of skinks is higher in arid environments compared with wetter areas (such as the Travis Wetland), possibly because of reduced predation pressure in dryer areas (Pianka, 1973). The current lizard species present at the Travis Wetland may not reflect the potential species diversity. In the past, as is indicated by the Canterbury Museum Collection Records, there may have been around three more lizard species present in the urban Canterbury area (Freeman & Freeman, 1996). The common gecko (*Woodworthia maculata*), jewelled gecko (*Naultinus gemmeus*), and spotted skink (*O. lineoocellatum*) could be reintroduced to the wetland to increase the biodiversity of lizard species (Bell, 2014; Freeman & Freeman, 1996). These lizards have been observed in Christchurch city in the past (Freeman & Freeman, 1996; McCann, 1955).

Skink Nomenclature

The naming, definition, and identification of skinks is quite complicated (Bell, 2014; Patterson, 1985; Patterson & Daugherty, 1990; Patterson & Daugherty, 1995). Around 1977, it was discovered that mainland and Chatham Island populations of the so called common skink were distinct from one another (Liggins et al., 2008; Patterson & Daugherty, 1990). It was decided that *Leiopisma nigriplantare nigriplantare* were the Chatham Island population and *L. n. polychroma* were the mainland and Stewart Island population (Patterson & Daugherty, 1990). Within the *L. n. polychroma* variation, there was morphological, ecological, and genetic diversity so it was suspected there may be more division of species in the future (Patterson & Daugherty, 1990). In 1995 a paper was released to reinstate the use of the genus *Oligosoma* instead of *Leiopisma* for New Zealand skinks as they were found to be morphologically different from skinks found overseas (Patterson & Daugherty, 1995).

Previous studies have called many potentially distinct skinks by the same name; the New Zealand common skink (*Oligosoma nigriplantare polychroma*) (Liggins et al., 2008). Freeman and Freeman (1996) and Morgan (2002) use *O. n. polychroma* to describe the skink found in the Travis Wetland area and call it the common skink based on the previous literature.

More recently the Chatham Island skink has been named *O. nigriplantare* and the mainland skink named *O. polychroma* (Bell, 2014). For *O. polychroma*, tag names for five different clades have been given to suspected distinct species (Bell, 2014). Clade 1 is the Northern grass skink (*O. polychroma*) and is found in the North Island (Bell, 2014; Nelson-Tunley et al., 2016). In the South Island there are the Waiharakeke grass skink (*O. aff. polychroma* Clade 2) found in the North-eastern areas, South Marlborough grass skink (*O. aff. polychroma* Clade 3) found in North Canterbury and central parts of Marlborough, and the Canterbury grass skink (*O. aff. polychroma* Clade 4) found in Central Canterbury and the West Coast. The Southern grass skink (*O. aff. polychroma* Clade 5) is found in damp parts of Canterbury, Otago and Southland (Bell, 2014).

(Distribution information from: <http://rarespecies.nzfoa.org.nz/fauna/lizards/>. Accessed 21/11/2018).

For my study I will use “*O. polychroma*” or “grass skink” to describe any grass skink found on the mainland for simplicity and because past studies have used various names for potentially the same species.

Grass Skink Conservation Status

The Northern grass skink is not threatened as there are large, stable populations, but is it conservation dependent (Hitchmough et al., 2013). On the South Island, the Waiharakeke grass skink has a large population covering less than 10 000 ha (100 km²) and is predicted to decline 10-50% (Hitchmough et al., 2013). South Marlborough, Canterbury, and Southern grass skinks have very large populations and are widespread covering >10 000 ha (100 km²), but they meet the criteria for being at risk and are predicted to decline 10-70% (Hitchmough et al., 2013). Any locally small populations may be at risk of extirpation.

Abundance

The abundance of the grass skink has been estimated in urban Christchurch in the past, but not recently. At two sites in the Travis Wetland, Freeman & Freeman (1996) captured a total of 16 skinks in 50 pitfall traps over 21 days and observed 27 others. They started with 20 traps in each of two locations but added 10 traps for a total of 50 traps after the study had started in one of the study sites as the traps already there were not catching any skinks. Traps were placed in willow, grassland, and mixed willow/grassland areas within the two sites. No skinks were caught in the mixed or willow areas. However, five skinks were observed in mixed areas.

Reproduction and Snout-to-vent Length (SVL)

Freeman (1997) studied the ecology of grass skinks in Central Otago and Kaitorete Spit, Canterbury and found they are diurnally active summer breeders. The minimum SVL for grass skinks to reach sexual maturity is around 40 mm and their mean clutch size is 5-6 eggs (Spencer et al., 1998). Their maximum SVL is around 77 mm (Gill & Whitaker, 1996; Lettink & Cree, 2007). New Zealand lizards have low reproductive output so when faced with predation threats, they are at high risk of population declines (Norbury, 2001).

Diet

The diet of grass skinks is mainly insectivorous, followed by spiders and then fruit (Freeman, 1997). Their diet includes Araneae, Coleoptera, Lepidoptera, Diptera, Hemiptera, and arthropod eggs (Freeman, 1997; Spencer et al., 1998). The grass skink is a diet generalist, but also shows some selectivity such as avoidance of ant consumption (Freeman, 1997). Lizards are important as they can take fruit from divaricating plants, as no other frugivore can get to the often-inconspicuous fruit within dense interwoven branches (Flux, 1985; Whitaker, 1987; Wotton, 2002). They consume fruit from *Coprosma propinqua*, a fast growing shrub found all over the Travis Wetland (Freeman, 1997; Wotton et al., 2016). The common gecko (*Woodworthia maculata*) is a major frugivore of *C. propinqua* and they provide it with effective seed dispersal (Wotton et al., 2016), and other lizards may be having similar positive impacts of seed dispersal.

Vegetation

Freeman & Freeman (1996) captured a total of 16 skinks (*O. polychroma*) all in grassland habitat, consisting of mixed grassland with native and introduced species. There were four skinks at their Long Island site which was a grass-rush wet pasture. They caught more skinks, 12, at the Manuka site which is rush-sedgeland. The grass skink prefers open areas with low vegetation such as tussocks and other grasses as its striped patterns may provide camouflage (Freeman & Freeman, 1996; Patterson & Daugherty, 1990). The Northern grass skink avoids shady habitats and large boulders (Townes & Elliott, 1996). They prefer few boulders, grass and herb cover compared with shrub and forest cover (Townes & Elliott, 1996). The preferred tussock grassland habitat of the grass skink differs from the similar McCann's skink *O. maccanni* habitat which consists of herbs, shrubs, and rock outcrops (Freeman, 1997; Freeman & Freeman, 1996). The common gecko is often found in trees in forested areas (Wotton et al., 2016). The jewelled gecko (*Naultinus gemmeus*) prefers dry understorey forest habitats (Jewell & McQueen, 2007). The spotted skink (*O. lineoocellatum*) is found in stone cracks surrounded by shrubs and grasses (Frank, 2012).

Methods for Estimating Lizard Abundance

Some trapping can be lethal, such as using pitfall traps with the preservative ethylene glycol which reduces any chance of the study species escaping the trap (Norbury et al., 2009), but is otherwise not an ideal method to use especially when measuring abundance for conservation purposes. Non-lethal funnel traps, pitfall traps, and artificial shelters will be reviewed.

Mark-recapture methods are often used for estimating skink population numbers where repeated samples are drawn from the population (Efford & Fewster, 2013). The animals are trapped, marked in some way, and then released afterwards. Paint or pen marks only last until the skink sheds its skin, so any natural marking such as scars or tail regeneration are also noted (Gebauer, 2009). A capture history is gathered which allows an estimate of the unsampled proportion of the population, and together with the sampled proportion gives the total estimate of abundance (Efford & Fewster, 2013). One continuous trapping grid, or clusters of traps, placed over a large area should be used to be most representative of abundance (Efford & Fewster, 2013).

Enge (2001) compared the effectiveness of pitfall versus funnel traps in the USA. Their pitfall traps were 34 cm deep 19-litre plastic buckets, and funnel traps were 86 cm long and made from aluminium window screening. In four out of five of their experiments, lizards were captured significantly more often in funnel traps compared with pitfall traps. However, at a species level the results were varied. The mole skink, *Eumeces egregius*, was captured significantly more often in pitfall than in funnel traps (Enge, 2001). The mole skink is endemic to the United States and prefers sand hills and scrub, often burying underground.

The NZ grass skink is a similar size to the mole skink, and studies in the past have successfully used pitfall traps to estimate their population abundance (Freeman & Freeman, 1996). Enge (2001) warns that small lizards may be at risk of drowning and hence have higher mortality in pitfall compared with funnel traps. This can be reduced with drainage holes, addition of sponges, cloth, and/or a layer of dirt to absorb water as well as checking traps more often. Checking traps daily in wetland habitats can help to maximise survival of species at risk to drowning (Enge, 2001).

Freeman and Freeman (1996) used a total of 50 pitfall traps at two different sites (Long Island and Manuka) at the Travis Wetland and placed them in willow, grassland, or willow/grassland vegetation types. The traps were made from 30 cm deep “Raro” and “Milo” tins baited with tinned pear. A lid with a 1 cm gap was placed above the traps to reduce predator and water access. To distinguish skinks, Freeman & Freeman (1996) took photos of dorsal and ventral patterning and colouration. In particular, speckling and stripes were noted. The traps were left in the ground for a week before being baited for a 21-day period. Over this period, Freeman & Freeman (1996) checked the traps seven times. They found no skinks residing in the willow area, as the skinks seemed to prefer grassland, with places for basking. If the traps were checked every day, capture rates may have increased (Enge, 2001).

A study in the Eglinton Valley (Fiordland, South Island) used pitfall traps and artificial retreats to estimate skink population size (Lettink et al., 2011). The accuracy of single-day index counts of grass skinks from artificial retreats was compared with mark-recapture estimates from pitfall trapping. Their pitfall traps were 4.5 L square plastic containers from Containment Solutions, Christchurch (dimensions not given). Plywood lids were used with a gap made using steel pegs. They added 1 cm³ of tinned pear every second day to their traps, and vegetation, soil, and stones to provide cover. Early summer was found to be the ideal time to trap skinks because it avoided the main birthing period, and temperatures were an optimum 12-18 °C (Lettink et al., 2011). Marking skinks with a pen (type not specified) was not successful as a marking method as the mark disappeared within 1-6 days (Lettink et al., 2011). Instead, toe-clipping was done using sharp nail scissors. The grass skink loses toes naturally so individuals which already had missing toes were used in the marking system (Lettink et al., 2011). However, it can take a long duration for the lizard to recover from the loss, which may inhibit normal movement and behaviour (Johnson, 2005). Their artificial shelters were made from 42 x 67 cm sheets of layered brown Onduline (corrugated fibrous bitumen) roofing material, stacked in sets of two or three with spacers between the sheets, and all weighed down with rocks (Lettink et al., 2011). Skinks were not marked for these experiments, so numbers were skink sightings, not numbers of separate individuals. Over two years, pitfall traps resulted in a count of 506 skinks and artificial retreats resulted in a count of 866 skinks. When sampling was completed during optimal weather conditions, the artificial retreats provided a reasonably accurate index of population size (Lettink et al., 2011). However, there is a risk that skinks develop an aversion to the artificial shelter if the Onduline is turned over too often (Lettink et al., 2011) and being a fibrous material, it may lose its structure in wet environments (Lettink & Cree, 2007).

The results from this skink abundance study were tied in to the prey retrieval study in Chapter 4. If there was a low number of skinks caught in pitfall traps and a high number of dead skinks brought home by cats, then there would be a clear problem of cat predation. The number of skinks caught in pitfall traps was provided and the population abundance estimate was compared with Freeman & Freeman (1996) to see how the population size has changed. The range and average SVL were given, and finally the results from the cat prey retrieval and GPS studies were used to help draw conclusions about the risk to the population.

I aimed to see if the skinks were more abundant towards the center of the wetland, away from zones where they would be at risk from cat predation. I hypothesised that skink

population will be either lower compared with Freeman & Freeman (1996) because of high cat predation, or higher because of the continued volunteer efforts in removing willow trees which may increase suitable skink habitat.

5.2 Methods

Skink abundance was estimated using pitfall traps as they were deemed more suitable than funnel traps or artificial retreats for use at the Travis Wetland (Figure 5.1). Using similar methods to Freeman & Freeman (1996), forty ice cream buckets, 20 cm deep (18 cm x 18 cm), were used. Holes were drilled at the base of the buckets to allow for any water to drain away (Enge, 2001). The traps were placed at four different sites, two in the middle, and two at the edges of the Wetland (Figure 5.2). Traps in the middle were in grassland and traps at the edge were in mixed willow/grassland areas. The middle sites were chosen to be largely surrounded by open water, which could potentially restrict the movement of mammalian predators into the wetland. At each site ten traps were placed in a line at least 5 m apart. The traps were baited with 1 cm³ pieces of tinned pear with a lid on top with a 1 cm gap for skinks to enter (Freeman, 1997; Whitaker, 1967). The lid protected the lizards from predation and weather events (Freeman & Freeman, 1996). A stick was placed in the buckets while the traps were not in use to allow any caught skinks to leave (Freeman & Freeman, 1996). Once trapped, skinks were picked up and moved to a larger container for easier handling. Skinks were handled, to measure snout-vent length (SVL), tail length and tail regeneration for identification. SVL was measured with a clear ruler to the nearest 1 mm (Freeman, 1997). Skinks were marked with a unique number on their ventral surface with a xylene-free silver marker pen (Dumont, 2015; Wilson et al., 2007) for mark-recapture estimates, and photographs were taken of their dorsal and ventral sides as well as from their lateral side from nose to forelimb in case of skin shedding (Freeman & Freeman, 1996). The warmest months in New Zealand are December, January, and February. For 20 days during February, after traps had been in place for a week with a stick, the stick was removed and traps were baited regularly and checked every day to maximise capture rates and reduce mortality (Enge, 2001).

For the mark-recapture method, at least one individual would need to be recaptured for the equation $(M \cdot C)/R = N$ for the Schnabel Method (Krebs, 1989) where:

N = an estimate of the true number (N) of individuals in the population at the time of initial marking.

M = the number of individuals in the population that have been marked at the time of the current sampling.

C = the number of individuals captured at the current sampling.

R = the number of individuals recaptured at the current sampling.

If there were no recaptured skinks, the equation would not be needed because the approximate population is the caught amount.

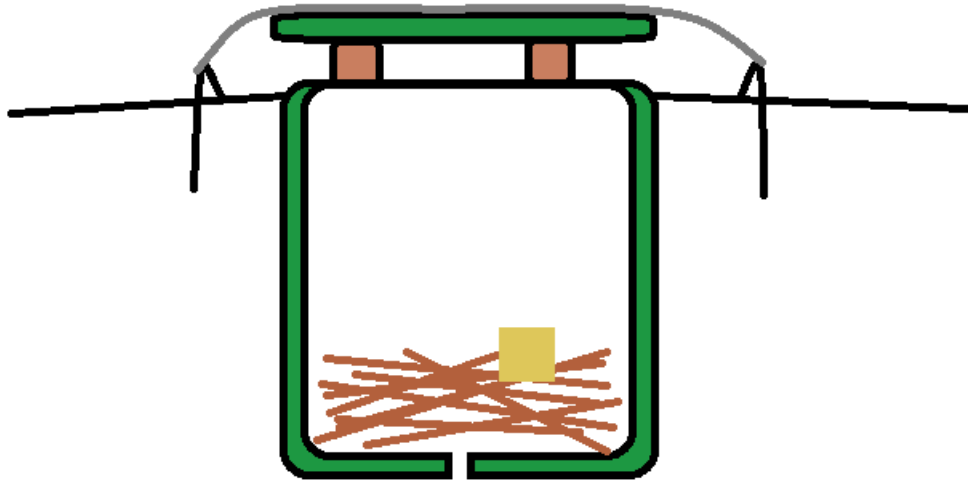


Figure 5.1. This is a representation of the 20 cm (18 x 18 cm) deep ice-cream container pitfall trap. The trap and lid were spray painted green to blend in with the surrounding grass. Nearby grass and twigs were placed at the bottom of the trap with a pear cube. The lid had a 1 cm gap created with wooden stakes and was held down with wire and U-shaped wire pegs.

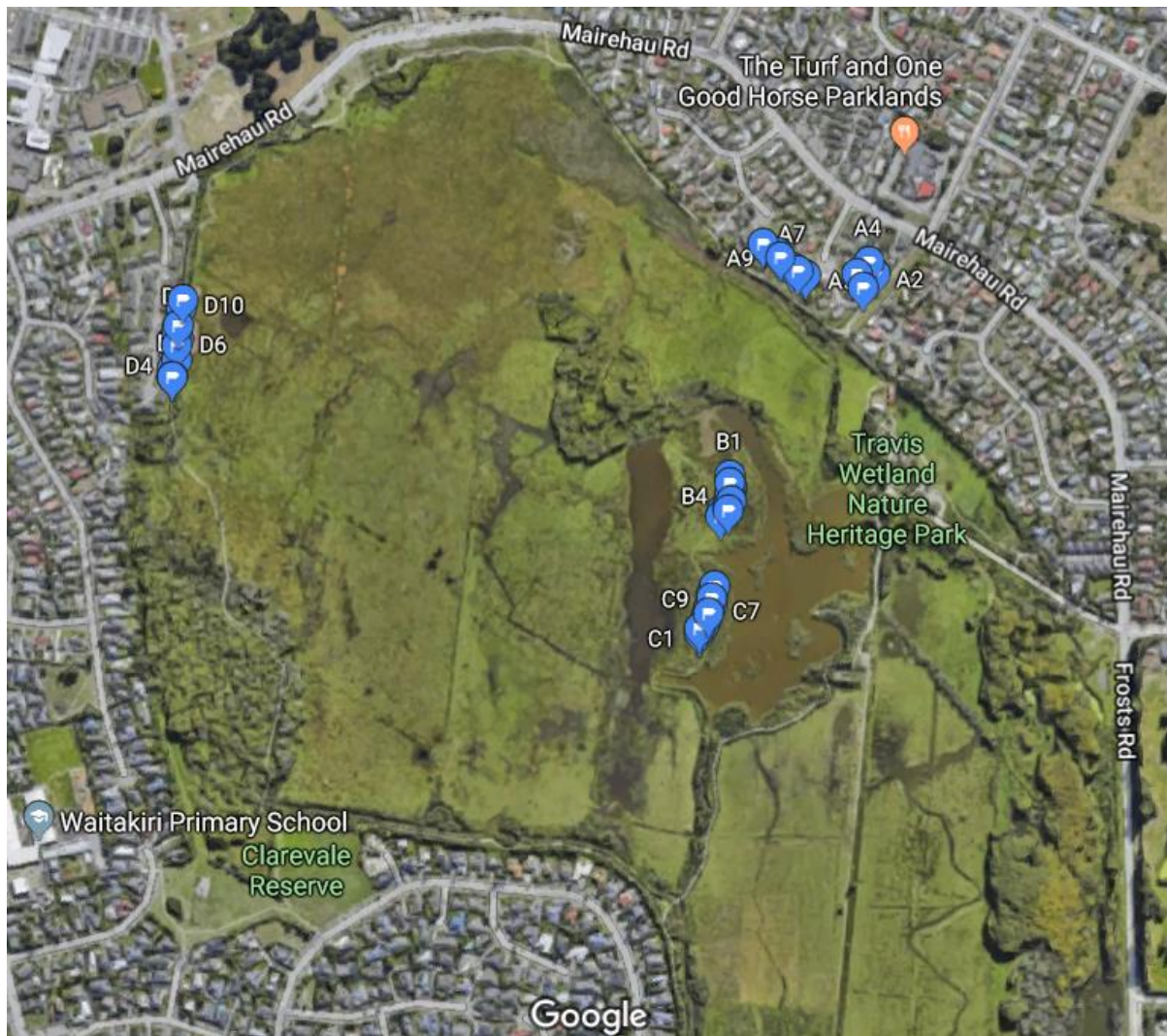


Figure 5.2. Four locations of the traps with 10 traps at each location in the Travis Wetland, Christchurch, New Zealand. Sites A and D are located on the edge of the wetland and B and C are in the centre. Waypoints obtained from GPSmap 60CSx GARMIN. Image from Google Maps.

5.3 Results

Number of Skinks

Over the 20 days of trapping, a total of 11 skinks were found in the traps and 9 were seen outside of traps. No skink was found together with another skink, and none were captured more than once so the mark-recapture equation could not be carried out. There are therefore at least 11 skinks in the trapping areas. All skinks were identified as Southern grass skinks (*O. polychroma*; Marieke Lettink, pers. comm.). Juvenile skinks were defined as snout vent length SVL being < 42 mm (Dumont, 2005; Freeman, 1997). Therefore 4 out of 11 (36%) of the skinks caught were juveniles.

Specific Skink Locations

Over the trapping period, skinks were found in seven of the 40 traps. Out of the 11 skinks, 5 (45.5%) were caught in the edge traps and 6 (54.5%) in the centre. On the right edge of the wetland, one skink was found in trap A1. At one of the centre locations, two were caught in

B1 (one of these shown in Figure 5.5), one was caught in B3, and one in B4. At the other centre locations, two skinks were caught, one in C10 and one in C4. The edge traps, D9, caught 4 out of 11 (36%) of the skinks, two juveniles and two adults. One of these skinks is shown in Figure 5.6. The other two juveniles were caught in the centre traps.

The nine skinks observed outside traps were seen during four different days and may have included the same skinks multiple times. Skinks were not actively searched for as in the Freeman & Freeman (1996) study, so comparisons cannot be made. The day before trapping officially started when sticks were removed, and bait added, a skink was found in the C3 trap. On day 9 two skinks were observed running away within 1 m of trap C5, one skink was observed on the lid of C10 and another on the lid of C1. On day 12 one skink was seen near B5. On day 17 two skinks were seen by trap C4 and one was seen by trap B10.

Vegetation Near Traps

Traps which caught skinks had grass, shrubs, small trees and were usually dry and sunny (Figure 5.3). Traps which did not capture skinks included the site D location where they were mostly under trees and shade for most of the time. The one trap which captured skinks at site D was more open with shrubs, grass, small rocks, and sun access.

a)



b)



c)



d)



e)



f)



g)



Figure 5.3. Trap locations where skinks (*O. polychroma*) were caught at the Travis Wetland, Christchurch, New Zealand. a) Trap A1 - One skink. Grass, shrubs, small tree, and fence. b) Trap B1 - Two skinks. Grass and shrubs. c) Trap B3 - One skink. Grass and shrubs. d) Trap B4 - One skink. Grass and shrubs. e) Trap C4- One skink. Grass, shrubs, and one tree. f) Trap C10 - One skink. Grass and shrubs. g) Trap D9 - Four skinks. The nine other traps in this location were under trees and were in the shade most of the time. The D9 trap was in an open area where there were shrubs, grass, small rocks, and sun access. Traps which caught skinks C4 and B3 stayed dry throughout the study (except on the last day).

Trap Flooding

The Travis Wetland is a very wet environment. Flooded or semi-flooded (at least 1/3 flooded) traps were not able to capture skinks so were excluded from number of trap nights. A total of 42 trap nights were excluded for this reason. When traps were discovered to be wet they were reset by emptying the water and replacing the trap in the hole if appropriate or moved to a nearby location ~2 m away if the hole was flooded too.

On day one multiple traps were at least partly flooded due to heavy rains. Centre traps C1-10, except C2, 4, and 5, needed to be reset. Centre traps B1, 2, 4, and 6 also needed to be reset. On day 10 centre traps C1-10, except C4, needed to be reset due to heavy rains. Traps B1, 2, and 6 also needed to be reset. Day 19 was the arrival of Cyclone Gita and all traps were damp (it was raining heavily) but none needed to be reset. On day 20 all middle site traps (B and C) flooded except B10. All side sites (A and D) were damp but not flooded.

Population Abundance Estimate Comparison

To estimate whether the local skink population is stable, rising, or declining, a χ^2 test was carried out comparing my study to the Freeman & Freeman (1996) study. Freeman & Freeman (1996) had forty traps set for 21 days and 10 traps set for 7 days for a total of 890 trap nights. My study had 20 days with 40 traps for a total of 800 trap nights. Removing 42 trap nights where traps were flooded gave a total of 758 trap nights. In 1996 16 skinks were caught and there were 874 trap nights where no skink was caught. In 2018 there were 11 skinks and 747 trap nights without skinks. There was no evidence that skinks have become significantly less common ($\chi^2 = 0.305$ and P-value = 0.581), with 1.8 skinks per 100 trap nights in Freeman & Freeman (1996) compared to 1.3 per 100 trap-nights in my study.

To see if number of skinks caught were significantly different between edge and centre sites in my study, a χ^2 test was carried out. There were 20 days with 40 traps for a total of 800 trap nights. The edge sites were all dry so trap nights where no skink was caught was 794 as five skinks were caught. Removing 42 trap nights where traps were flooded/semi-flooded for the centre sites gives a total of 752 trap nights where no skink was caught as six skinks were caught. There was no evidence of a difference in abundance at edge or centre sites ($\chi^2 = 0.154$ and P-value = 0.695).

Snout Vent Length (SVL)

The range of SVL in my study was 29 mm – 67 mm with an average of 47 mm. Only two of the skinks had tail regeneration, one with 35 mm (trap A1) and the other with 26 mm (trap D9).

Cat Prey Retrieval and GPS Studies

During the study where prey items brought home by domestic cats in the study area was recorded, no skinks were recorded. The study lasted 6 months and 41 cats participated, yet none brought home skinks. This is compared with the Morgan (2002) study where 88 cats over one year brought home 172 skinks. From the GPS tracking study and radiotracking from Morgan (2002) it shows that cats do not go far into the wetland, so are most likely to be catching prey from their backyards or close by.

Cat Sightings

While checking traps for skinks, many cats were observed resting, socialising, or moving through the wetland and these sightings were noted down (Figure 5.4). On day four a cat was seen looking at a bird and then walked off near trap D10. On day five a grey cat was seen between traps A3 and A4. Near A5 a cat was seen walking into the wetland. On day six a grey cat was seen between traps A9 and A10 entering the wetland through the trees. On day 12 two black cats were seen entering the wetland near traps A1 and A10. On day 13 a cat was seen near trap C10. Day 15 saw two black cats (possible same as on day 12) near A traps, one near the road and one on path near A7. On day 17 a grey and white cat was seen sleeping near trap A1. On day 18 the same grey and white cat sleeping near trap A1. A black and white cat and grey cat entered the wetland near trap A10 and a black cat sat on the fence watching them. Around 15 cats total were seen during the 20 days of trapping.



Figure 5.4. Domestic cat resting at the edge site A at the Travis Wetland.



Figure 5.5. Southern grass skink no. 4 caught in the centre of the Travis Wetland in trap B1.



Figure 5.6. Southern grass skink no. 8 with visible trail regeneration caught in trap D9 at the edge of the Travis Wetland.

5.4 Discussion

Number of Skinks and Population Abundance Estimate Comparison

The number of skinks caught was not significantly different in the Travis Wetland compared with Freeman & Freeman (1996) so there was insufficient evidence to suggest the population is declining or increasing. Skink numbers may not have decreased due to successful management of the Travis Wetland, where invasive plants such as willow are removed. However, the number of skinks captured does not reflect actual number of skinks in the entire wetland, only those specific areas tested. Similar to Freeman & Freeman (1996) the number of skinks caught in total was very low. Numbers may have been low in the edge sites because of cat predation and they may have been low in the middle sites because of unsuitable trap placement, but there was no significant difference in numbers between the two sites. There were juvenile skinks in both the centre and edge locations so reproduction is being carried out successfully even where cats may have access. The middle sites chosen were the driest area found in the vicinity of the open water, as all surrounding area was swampy. Traps were placed in what was thought to be dry areas, but they often flooded after heavy rains. Skinks were present at all four sites, but in low numbers. Trap D9 was the only trap that caught skinks on the left edge set of traps. The D traps were all under cover from forest but trap D9 was the only one in the open surrounded by shrubs, grass, and small rocks which may have been why it caught skinks.

Population estimates obtained for lizards tend to be difficult to work out and may not reflect actual abundance due to the lizard's cryptic nature and territorial behaviour (Towns and Elliot, 1996). In my study skinks were alone in traps, a similar finding to that of Lettink and Cree (2007) where skinks were alone, within a group of geckos, or with one other skink. Geckos on the other hand often group together for reasons such as increased mating

opportunity, increased vigilance against predators, and improved thermal conditions (Lettink & Cree, 2007).

Snout Vent Length (SVL)

Other studies SVL ranges are 31 mm – 66 mm (Freeman, 1997), 25 mm – 65 mm (Lettink & Cree, 2007) and 22 mm – 76 mm with an average of 49.6 mm (Dumont, 2015). The skinks in my study had a similar range of sizes. The only skinks with tail regeneration were found in sites A and D, the two edge sites. They most likely lost their tails through caudal autotomy (Cromie & Chapple, 2012). As these skinks were found on the edge sites, they may have been escaping from the cats that use the walkways to get around.

Cat Prey Retrieval and GPS Studies

In the study carried out in the Travis Wetland area in 2000-2001, 88 cats brought home 172 grass skinks over one year, which was 18% of their total prey (Morgan, 2002). My study had 41 cat participants and lasted 6 months. During this time no skinks were brought home. There were 9/14 (64%) cats that were tracked with GPS that entered the periphery of the wetland. No cats ventured further in than the periphery. From Chapters 2 and 3 (cat abundance and GPS sections) there is an estimated 245 – 275 cats that enter the wetland periphery. These cats may potentially kill and consume skinks around the wetland walkways. In a study in the USA using video cameras on cats, it showed that only 23% of the prey items were brought home (Loyd et al., 2013). The cats in my prey retrieval study may have killed skinks in situ. Skinks around household gardens are also at risk as that is where cats spend the majority of their time.

Skink occurrence has been found to be associated with lower cat densities (van Heezik & Ludwig, 2012). Removing predatory mammals from an area can increase the survival and abundance of skinks (Wilson et al., 2017). However, skinks in the Travis Wetland area appear to have a stable population and are relatively safe in the centre of the wetland compared with the edges. There are other predators present such as rodents and birds that may prey on skinks, but the wetland provides plenty of refuge for these lizards. Removing cats by creating exclusion zones (Metsers et al., 2010) or keeping them indoors only may have detrimental outcomes for skinks if rodent populations increased (Rayner et al., 2007).

Importance of Lizards

Lizards may be important seed dispersers as they move seeds which allows them to escape parent plants (Wotton et al. 2016). Different species have distinct habitat preferences so a larger diversity of lizards in an area may increase overall seed dispersal rates, as more habitats are utilised (Freeman, 1997). Grass skinks prefer tussock and grassland (Freeman & Freeman, 1996) and the common gecko often climbs trees (Wotton et al., 2016). The jewelled gecko is found in forest habitats (Jewell & McQueen, 2007) and the spotted skink is found in areas with stone, shrubs, and grasses (Frank, 2012). These lizards could be reintroduced to the wetland to increase the biodiversity of lizard species as they have been observed in Christchurch in the past (Bell, 2014; Freeman & Freeman, 1996; McCann, 1955).

Creating Lizard Sanctuaries

Providing long lasting habitats for lizards is important for lizard survival and can increase their abundance and diversity. Along with providing natural habitat such as dry, sunny, protected areas with suitable fruiting plants, artificial shelters can be provided. Shelters can be made from Onduline roofing material, stacked in sets of two or three with rocks or other spacers between the sheets, all weighed down with rocks (Lettink et al., 2011). However, because Onduline is a fibrous material, it may get soggy in wet environments and should only

be used in dry areas like household gardens (Lettink & Cree, 2007). In the Travis Wetland suitable materials may be slate, rocks, or concrete tiles as these would provide dry areas for the lizards where they can thermoregulate (Lettink & Cree, 2007). Already a couple of sanctuaries have been set up near the Travis Wetland Ranger's house, one consisting of old house pile materials and another which has been dubbed a 'skink motel' using slate from the Halswell Quarry (Figure 5.7 and 5.8). There are very few rocks in the Travis Wetland, so bringing them in from elsewhere and strategically placing them in dry sites near high insect and fruit abundance areas would greatly improve the chance of lizard survival (Freeman, 1997). Skinks are seen occasionally sitting on the edge of the wooden boardwalk that circles the wetland. Providing artificial habitat around other areas of the wetland may provide more suitable habitat. Skink presence has been associated with low cat densities, low plant species diversity, short distances to cover, and surprisingly more long exotic grasses and less native vegetation (van Heezik & Ludwig, 2012). However native divaricating shrubs are important for lizards as they provide nectar or berries as a food source (Whitaker & Gaze, 1999). Lizards can be effective seed dispersers of these shrubs (Wotton et al., 2016). Another food source is insects and minimising pest spraying can increase insect availability for lizards (Whitaker & Gaze, 1999).

Future

In the future, more suitable habitat should be made available in the Travis Wetland so that grass skink abundance stays stable or increases and skink diversity could increase. Small populations, such as the skinks in my study, are at risk of becoming locally extinct from predation impacts (Jones & Bell, 2013; Norbury, 2001). However, the areas chosen for my study were areas that cats were more likely to access on the edge of the Wetland, compared with a central area to see the effects of cat predation. To gain a better estimate of skink abundance, a future study could choose a larger amount of study sites, focusing on areas where skinks are most likely to be. The forested areas on the left edge of the wetland were not suitable skink habitat as the grass skink prefers open habitat (Freeman & Freeman, 1996; Patterson & Daugherty, 1990), and no skinks were caught under forest covered areas in my study. There were no skinks caught in the willow and mixed willow/grassland areas in the Freeman & Freeman (1996) study so heavily forested areas should not be tested in the future for the presence of grass skinks. No skinks were brought home by cats in the prey retrieval study, and cats did not venture far into the wetland. Therefore, trapping skinks in household backyards may give an indication whether skinks are present or not in neighbourhood areas. Households should be encouraged to set up skink friendly areas in their backyard, perhaps using Onduline roofing material, or even just rocks (Lettink & Cree, 2007).

a)



b)



Figure 5.7. “Skink motel” by the Travis Wetland ranger house. These sanctuaries been dubbed skink motels by the Travis Wetland Rangers. The slate is from the Halswell Quarry. A) looking towards the ranger house. B) looking towards the wetland.



Figure 5.8. Skink sanctuary made from rock piles from the old Travis Wetland ranger house, placed prior to the skink motel in Figure 5.7.

Chapter 6: Discussion and Conclusions

6.1 Impacts of Cats on Urban Wildlife

Cat Characteristics Summary

My study had 33 males and 41 females (1:1.24) compared with Morgan (2002), which featured fewer females (1:1.04). In my study cat age was between 3 months and 18 years with a mean of 7.86 years whereas in Morgan (2002) cat age ranged from 1 month to 16 years with a mean of 6 (± 4 sd). Around 10% of cats wore a collar and bell in my study, much less than the previous 18%. People may realise they do not have much of an effect on reducing cat predation.

Travis Wetland Wildlife

In my study 9 out of 14 (64%) cats visited the wetland, whereas 11 out of 21 (52%) cats entered the wetland during Morgan (2002) study. None of these cats went into the centre, only the periphery. While trapping skinks in the centre of the wetland during my study one cat was seen, and Morgan (2002) said cats have been sighted in internal parts of the wetland in the past. She thought that cats may be using the wetland for socialising and resting, only partly for foraging. During my study cats were seen resting in grassy areas on the wetland periphery. Morgan (2002) estimated there were between 170 and 260 cats that may be entering the wetland. I have estimated that between 245 and 275 cats out of the approximate 429 cats in the study area may enter the wetland, a similar but slightly higher range.

Morgan (2002) found that all cats tracked that entered the wetland also brought home prey, but in my study not all cats that entered the periphery brought home prey. Of the 14 cats tracked, 13 participated in the prey retrieval study and 6 brought home prey (46%). For the cats which entered the wetland, five brought home prey (55%) and then half of the cats that did not enter brought home prey. Four of the cats tracked lived on the periphery of the wetland and two brought home prey, one being Max the superpredator who brought home 45% of the total prey. Four out of nine cats not living on the periphery brought home prey (44%). Cats in my study brought home an average of 3.21 prey items per cat per year compared with 11.5 (8.64 when invertebrates excluded) in Morgan (2002) study. This may reflect the reduced number of wildlife in urban areas as there was more prey retrieved by cats in the summer of 1999/2000 than 2000/2001 in Morgan (2002) and the trend may have continued.

Using percentages of prey brought home and estimates of cat numbers entering the wetland, estimates can be made on how many cats could be catching prey from the wetland. There were 44% of cats that entered the wetland that brought home prey. Prey may not have been caught at the wetland, but assuming it was, for between 245 and 275 cats there may be between 109 and 122 cats bringing home prey from the wetland. In my study 42 prey items were brought home by 41 cats over 6 months. There were 22 prey items brought home by nine cats that entered the wetland to the periphery. Prey per cat per year was 4.89 (± 4.15). Assuming prey was brought home from the wetland, using the average and estimated cat numbers, it is estimated between 1198 and 1344 prey items are brought home per year by cats living around the Travis Wetland. However only 23 to 50% of prey is brought home by domestic cats (George, 1974; Loyd et al., 2013) and the rest is left at the capture site or consumed (Loyd et al., 2013). From these numbers, the total estimated prey killed per year by cats in the Travis Wetland, assuming the prey was brought home from there, is between 2396 and 5845 items. Even though one cat may only bring home one prey item over 6 months like

in my study, the addition of superpredators and the large number of cats in an area results in a large number of wildlife killed over time.

Morgan (2002) reported that predator monitoring carried out by Brom (2000) found more mice, rats, hedgehogs, ferrets, stoats, and cats around the wetland periphery compared with the wetland centre. She suggested they are present there in greater numbers because there is greater availability and abundance of prey around the edge of the wetland. Morgan (2002) observed greater numbers of stilt, pukeko, spur winged plover, mallard duck and Canada geese nests in the centre parts of the wetland compared with the periphery. She also references Freeman & Freeman (1996) to say *O. polychroma* skinks were most common on the periphery of the wetland, but they had only placed traps at the periphery. In my study there was no evidence of a difference in abundance of skinks at the edge or centre sites, disproving the hypotheses that skinks are more abundant towards the centre away from risk of cat predation, or more abundant at the periphery where the conditions may be preferably dry. Two of the skinks in my study had tail regeneration, one on the left edge of the wetland and one on the right. As these skinks were found on the edge sites, they may have been escaping from cats or other predators that use the periphery for hunting. Skinks were not found under willow areas, confirming their preference for open sunny spaces (Freeman & Freeman, 1996). Willow is being removed from the wetland by volunteers and skink sanctuaries have been created which will have positive benefits for the skinks. Morgan (2002) observed cats hunting pukekos, mice, and skinks right next to the walking tracks around the wetland. Birds and lizards in the centre of the wetland are therefore safer from predators. Native birds (silvereyes) were only a very small proportion of total prey intake and the other birds such as sparrows, and blackbirds have been found to be relatively well able to persist in the face of predation (Morgan, 2002).

Southern grass skink (*O. polychroma*/*O. aff. polychroma* clade 5) numbers in the wetland were similar to a previous trapping effort carried out in 1996 (Freeman & Freeman, 1996), disproving the hypothesis that skink abundance has decreased from previous heavy cat predation such as in the Morgan (2002) study. There were no skinks brought home by cats in my study compared with a large proportion (18%) brought home by cats 18 years ago (Morgan, 2002). The GPS tracking showed that cats were not going far into the wetland, only reaching the periphery areas. The lack of skinks brought home may reflect the lack of skinks residing on people's properties, not the wetland. Anecdotally, household owners shared experiences of often seeing lizards near their property in the past but said that they have not seen many, if any, lizards around their property or in general recently. Cats and other predators may have contributed to the decline of lizards in urban areas. Cats have been found to be effective predators of lizards (Fitzgerald, 1990; Morgan, 2002). Small populations of lizards, like in the Travis Wetland, are especially at risk as cats and other predators can potentially be the cause of their local extinction (Iverson, 1978; Jones & Bell, 2013; Nogales et al., 2006; Norbury, 2001; Whitaker, 1998). Cats, rats, mice, stoats, hedgehogs, and avian predators may all prey on *O. polychroma* (Hasegawa, 1990; Jones & Bell, 2013; Morgan, 2002; Norbury, 2001). The Travis Wetland, despite being an overall unsuitable habitat for lizards due to lack of dry, grassland areas, and large number of potential predators, may actually be a safe haven for lizards in the city. There are still some dry areas in the wetland and the newly created lizard friendly rock sanctuaries (skink motels) may help even further. Removing or reducing predators would help even further. Lizard population density, spatial distribution, habitat use, and body size may all increase when predators are excluded from their areas (Whitaker & Gaze, 1999). Body condition of skinks and reproductive output may also increase when predators are absent (Dumont, 2015). The Southern grass skink has been labelled "at risk" (Bell, 2014; Hitchmough et al., 2013) so management needs to be carried out so that populations do not decline.

City Wildlife

The 2011 estimate of domestic cats in New Zealand was 1.419 million (NZCAC, 2011) but more recently the estimate is 1.134 million (NZCAC, 2016). Morgan (2002) stated the June 2000 estimate of number of households in the Christchurch urban area was around 324,900 (New Zealand Population Dwelling Census, June 2000). Using this and other information, Morgan (2002) estimated annual predation by cats in Christchurch to be around 6,000,000 prey items caught per year. As of 2013, the most recent published Census, there were 129,100 households in Christchurch City (Christchurch city council). Morgan (2002) had used population size not household number.

If domestic cat demographics throughout the Christchurch urban area are similar to those around Travis Wetland (for my study 0.6 cats per household), then there would be approximately 77,460 domestic cats living in Christchurch City. The urban area of Christchurch is approximately 67,000 ha. The density of cats around the Travis Wetland area was 2.19 cats/ha (Chapter 2), so from this there is an estimated 146,730 domestic cats in Christchurch. The middle point of these estimates of 112,095 domestic cats will be used. Using the mean number of prey items known to have been retrieved per cat per year (3.21, Chapter 4), the estimated mean annual predation by the estimated 429 cats living around in the 196 ha area of Travis Wetland is around 1377 prey items per year and annual predation by cats living in the entire Christchurch urban area would be around 359,854 prey items per year. Since domestic cats probably only bring home between 23 and 50% of their prey (Loyd et al., 2013) annual predation by cats in Christchurch is probably closer to between 719,707 and 1,564,581 prey caught per year. This estimate is a lot lower than the Morgan (2002) estimate, but she did not use household number. If the prey selection of domestic cats elsewhere in Christchurch City were similar to that of the population around Travis Wetland, then domestic cat prey would consist of between 445,533 to 968,550 (62%) rodents, between 188,495 to 409,771 (26%) exotic birds, and between 85,679 to 186,260 (12%) native birds. These extrapolations are only approximations of the true predation in Christchurch City, and may only reflect prey composition of cats living near a natural reserve, but they provide some idea of the scale of impact.

More information is needed about the prey population dynamics otherwise we cannot know if the cats are having a large impact or not. Predation on mice, sparrows, blackbirds and silveryeyes by house cats and other predators in an urban environment does not cause a lot of concern as these species breed successfully despite predation (Barratt, 1998; Morgan, 2002). Barratt (1998) thought that if cats could control blackbird numbers in Australia, then less-aggressive native species could benefit, but they have not had a large impact on their population trends. Ogle (1982) found New Zealand forest bird species such as fantails and silveryeyes do well at thriving in remnant habitats in urban areas. The type and quality of habitats, the distance from suburbs to source habitats and the availability and diversity of urban habitat determines the richness and abundance of bird populations in urban environments (Green, 1984). Therefore, habitat availability may be more important in influencing bird populations in some urban areas than predation by domestic cats (Morgan, 2002).

Food Web Dynamics

If cat numbers are to be reduced, food web interactions must be considered. There are numerous predators in the Travis Wetland and many birds, skinks, and insects which results in numerous interactions. The mesopredator release example of Cook's petrel numbers decreasing after cats were removed from Hauturu and kiore had a population increase shows how careful management programmes need to be (Girardet et al., 2001). Domestic cats are opportunistic predators where they switch from one prey type to another depending on

availability (Fitzgerald, 1988; Lepczyk et al., 2003; Liberg, 1984; Loyd et al., 2013). Morgan (2002) found that house mice were the most common prey item brought home by cats, whereas my study found rats were preferred by the cats with 19 rats and 7 mice. Both studies, along with previous results, support the preference that cats have for small mammals (Bonnaud et al., 2007; Fitzgerald, 1988; Gillies, 1998; Morgan, 2002; Turner & Meister, 1988).

Cats may reduce number of rats and mice in the Travis Wetland (and surrounding household areas), which is a positive interaction. The reduction of rodents may benefit lizards and invertebrates as they are part of their diet (King, 2005). The presence of rodents however may protect bird species as larger predators may prey on them instead of birds. Too much trapping of rodents in the wetland could cause prey switching from them to birds, lizards, and invertebrates (Morgan, 2002; Sinclair et al., 1990). Stoats were caught by domestic cats in Morgan (2002) study, but not this one. The removal of cats from Travis Wetland area could result in the increase in other predators such as rodents, stoats, ferrets, possums.

6.2 Recommendations and Future Research

After the reserve was created, a water moat was created around the Travis Wetland to reduce the number of cats entering the wetland, but cats have been seen swimming or jumping across (Morgan, 2002). With the Morgan (2002) study radiotracking was used to see where cats go, but my study used GPS devices, a more powerful tool to see where cats are going. These two studies combined show compelling evidence cats are not regularly using the centre and are instead using the periphery of the wetland to socialise, rest, and occasionally hunt. However, to reduce the impact of cats on native wildlife that may be at risk of extirpation, such as skinks around the wetland periphery, management strategies need to be considered.

Cat Management Strategies

For free-roaming cats the options are eradication, adoption, keeping them in a sanctuary, and trap-neuter-return (TNR) (Levy & Crawford, 2004; Levy et al., 2003). Sanctuaries fill up fast and adoption often is not viable as the cats are not sociable (Levy & Crawford, 2004). Eradication is often needed to reduce the abundance of feral cats in forests where they may be reducing the numbers of birds (Fitzgerald & Karl, 1979). Shooting and trapping cats is often not a viable option as they are time- and labour-intensive methods (Short et al., 1997). Using 1080 poison has been found to be effective at reducing cat numbers in Western Australia, especially when prey abundance was low (Short et al., 1997). However, TNR is currently the preferred method to reduce the number of new cats in ecologically sensitive areas and in general (Levy & Crawford, 2004; Levy et al., 2003). Cats are neutered and then released, ceasing new births which naturally eventually reduces the size of the population (Levy & Crawford, 2004).

For domestic cats, management strategies have been created and include; neutering, keeping your cat indoors (cat confinement), creating cat exclusion zones, registering your cat, feeding them enough and providing enough enrichment so that they do not get bored and go hunting. Cats can be kept indoors day and night which benefits the cat and wildlife (Metsers et al., 2010). But this requires a lot of enrichment and commitment to making sure the cat is not bored and does not escape where they may not be street savvy. Cat exclusion zones are a way to reduce cat presence in certain areas (Gillies, 1998; Metsers et al., 2010). From the GPS home range study, the average can be calculated of how far cats travel to reach the Travis Wetland. Houses within this area could be required to not obtain any new cats and

people moving into the area could be required to not have a cat already. In the Morgan (2002) study most of her cats in her study lived within 200m of the wetland so she could not estimate cat buffer zone size. In my study cats which did not enter the wetland lived in a household between 200 and 260 m away from the periphery. Cats which did reach the wetland periphery lived between 20 (right next to wetland) and 230 m away. For an exclusion zone in this area, based off this data, cats would not be allowed in households 230 m away from the wetland or closer. The exception to this is that indoor only cats are fine in any situation. Using home range studies to find out how far cats travel is useful to apply to any situation where people live close to sensitive wildlife reserves. The addition of fences around wildlife reserves is another strategy to prohibit access from predators. Building a predator proof fence around the Travis Wetland may be extremely useful for protecting vulnerable wildlife. However, the initial cost of build and continuous upkeep cost mean this may not be a viable option for wildlife management. Cats do not appear to be going far into the wetland, so a fence may not be necessary however it would help to remove other predators.

Where cat confinement and exclusions are not an option, other ways to manage a cat include confinement but with access to the property only (restricted by cat proof fences), the addition of hunting deterrents on their collars, or the targeting of the most affective hunters. The BirdsBeSafe® collars and the CatBib™ have been shown to reduce the number of birds caught (Calver et al., 2007; Gillies & Cutler, 2001; Willson et al., 2015). Cats with Birdsbesafe® collars killed 19 times fewer birds in spring and 2.4 times fewer birds in autumn (Willson et al., 2015). The Liberator® is another option, a device which sends out audio-visual signals when the cat is about to pounce, and bells which may alert prey to the cats presence (Gillies & Cutler, 2001; Gordon et al., 2010). Attaching a bell to a cat's collar has been thought to help reduce their hunting, which is why many people use them. Many studies have found that collars with bells or alarms, such as the Liberator, are actually ineffective at hunting prevention (Barratt, 1998; Gillies & Cutler, 2001; Morgan, 2002). Morgan (2002) found that cats wearing a collar with a bell caught more prey than cats without a bell, showing how little effect they have on wildlife. The last option is to target the most effective cat hunter in an area, such as Max in my study, for management. That requires awareness of cat owners of the impact their cat is having on wildlife (van Heezik et al., 2010). Cats like Max which were catching mostly rats would be able to continue hunting, but cats with a preference for birds may need to be kept indoors.

Around 20% of the cats in my study were locked in at night and I looked into different reasoning behind this. In Australia there are dangerous predators to protect your cat from and valued native mammals to protect from your cat, so keeping your cat inside is often the best option (van Heezik et al., 2010). But there are no cat predators in urban areas in New Zealand and the only mammals brought home by cats are introduced rats and mice (King, 2005). An Australian study found that cats bring home birds in the morning, reptiles in the afternoon, and mammals in the evening (Meek, 1998a). Until rodent and other predator control is increased, domestic cats could help with predator control in New Zealand. A management strategy for cats would need to include management of all other predators linked within the food web.

Lizard Sanctuaries

The Southern grass skink *O. polychroma* has been labelled “at risk” (Hitchmough 2013). Of prey in the 2000 study 18% was this native skink but none were caught in my study, perhaps they were not present in urban areas outside of the wetland. Providing artificial habitats and improving the environment for lizards and other wildlife by reducing predator access is important for their survival (Dumont, 2015; Jones & Bell, 2013; Norbury, 2001). Artificial shelters nearer the center of the wetland that potentially increase skink abundance

may allow a more peaceful coexistence between cats and wildlife as they would be less likely to access those areas.

Repeating the study in the Travis Wetland after artificial shelters have been provided would be crucial to see if there is an increased number of skinks caught. Alternatively, supporting lizards in a more suitable habitat to begin with may be a more successful approach to making sure they thrive. The Port Hills may be a good location to focus on skink and gecko survival.

Conclusions

Cats are remarkable predators. They have excellent vision, even in low light which allows them to detect small prey movements, their hearing is more than three times more sensitive than humans which lets them detect the smallest squeaking of mice, and they have around 40 times more odour sensitive cells than humans which helps them to detect prey (Harper & White, 2008; Wilkins, 2007). They can easily stalk prey silently with their padded paws, and their retractable claws allow them to strike and grip their prey (Harper & White, 2008; Wilkins, 2007).

Simply managing cats may increase rodent abundance so all predators should be targeted in predator removal programmes. During the Middle ages when there were orders to kill all cats, there was subsequently a huge increase in rodent numbers across Europe, and rats carrying fleas infected with bubonic plague spread the Black Death (Wilkins, 2007). When cats were allowed again and kept as pets around the seventeenth century, rat numbers started to drop (Wilkins, 2007). If a cat exclusion zone was put in place around the Travis Wetland or other natural reserves, more intensive trapping of other predators would be to occur (Brom, 2000; Morgan, 2002). For free-roaming cats, predation on rodents and rabbits may help to keep their numbers low and reduce seasonal fluctuations (Fitzgerald & Karl, 1979).

Cats have only been in New Zealand for around 250 years, but numbers of domestic and free-roaming cats have reached the millions (King, 2005). Free-roaming cats can be considered invasive pests as they compete with native species for food, overpopulate areas, and have the potential to cause the extinction, extirpation, or decline of other species (Baker et al., 2008). Many native birds and lizards have not co-adapted with the recent introduced invasive species and many species only now reside on predator free islands (King, 1984). Domestic cats are not as numerous as free-roaming cats, but they can be directly managed by their owners and have a constant supply of food, reducing their impacts on wildlife. The Canterbury region was previously covered in wetlands which formed a huge estuary, but they were greatly reduced and replaced with dairy farms (Morgan, 2002). From 1780 to 1986 there was a huge extinction event in New Zealand where habitat destruction of wet forest and wetlands combined with predation by introduced mammals such as cats caused the decline of numerous birds and potentially other animals (Holdaway, 1989).

Food web dynamics as well as indirect effects on wildlife and the environment need to be considered when planning management programmes. *T. gondii* oocysts are shed from cat feces and spread through soil and water affecting numerous animals and birds including rats, kereru, and kiwi (Howe et al., 2013). When rats are infected, there is an increase in their trappability as the infection causes decreased neophobia and an increase in their activity (Tompkins & Veltman, 2015; Webster, 1994; Webster et al., 1994). Before removing cats from an area, rodents could be focused on, making sure there is *T. gondii* spreading through their populations so trapping rate is increased (Tompkins & Veltman, 2015). Cats need to be managed as unneutered cats breed which may result in neglected kittens and increased cat abundance. Fighting with other cats causes neighbourhood disturbance and they may dig up gardens and spray to mark their territories (Kikillus, Woods, et al., 2017). Other impacts are

competition for important food and space resources, changes in ecological systems, and behaviour changes of prey via induction of stress (Kikillus, Chambers, et al., 2017).

Managing cats is not just ecological issue but also social science issue. In a report by Kikillus et al. (2017) owners reported that their cat's hunting was not a problem (34%), that it was a small problem (22%) or big problem (5%), or that their cat did not hunt (24%). One quote from a survey respondent about their cat summed out how many people feel about cats:

“He was an important part of a happy childhood, taught me about responsibility for caring for another creature, about love and grief. I still love cats, and see people on their own, often elderly people, whose lives have great meaning and are enriched by owning and loving a cat, their cats are hugely important for good mental health and giving a reason to live, the benefit of having cats as friends outweighs the occasional trouble they cause” (Kikillus, Woods, et al. 2017, p 29).

Along with providing benefits such a companionship and amusement, cats help can also help reduce blood pressure by purring (Fitzgerald, 1990). Education campaigns can be created to control free-roaming cat populations. According to Morgan, *"Experience in Australia has been that public consultation is the most effective way to implement cat management and controls and results in more lasting changes in behaviour"* (Morgan 2002, p 95). The average amount of prey caught by domestic cats is significantly less than free-roaming cats without regular food provided to them (Churcher & Lawton, 1987; Fitzgerald, 1988; Gillies, 1998). Many households around the Travis Wetland are aware about the impact cats and other predators may be having on wildlife through participation in research studies, news articles, and television.

Around the Travis Wetland there were more houses and fewer cats and cats/household with a seemingly smaller overall impact compared with eighteen years ago. Cats brought home mostly rodents and no endemic birds and did not go far into the wetland (so brought home prey from closer to their household). In New Zealand, domestic cats in urban areas could stay out at night to help keep other predators in check until management programmes can target all predators. The 2050 Predator Free New Zealand Initiative created in 2016 to reduce the number of invasive species in New Zealand does not consider predatory domestic animals, so research on cats (plus other animals such as dogs and hedgehogs) is important to understanding their impacts on other wildlife (Kikillus, Chambers, et al., 2017).

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Appendix

Cat Tracking Participants



Batman/ID62



Cooper/ID74 (photo from owner)



Hunter/ID28



Nina/ID29



Oscar/ID39



Maxi/ID13



Bella/ID47



Mika/ID59 (photo from owner)



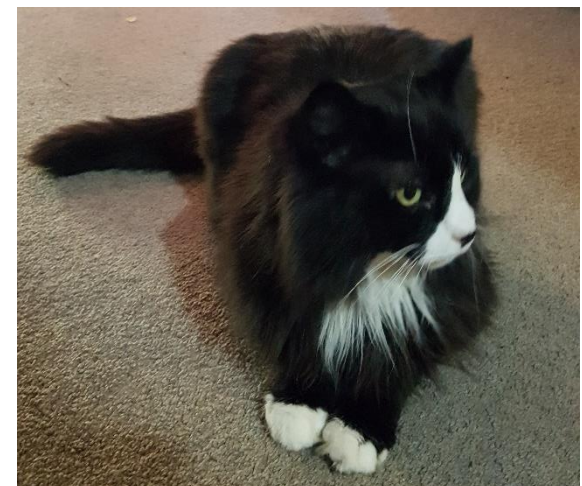
Munchkin/ID57 (photo from owner)



Millie/ID25



Poppy/ID69



Max/ID11



Roxy/ID42 (photo from owner)



Tigger/ID41 (photo from owner)

Cat Prey Retrieval Participants

Cat ID	Age (year)	Sex	Breed
1	4	F	1
2	12	F	1
3	11	M	1
4	12	F	1
5	18	F	1
6	17	M	1
7	8	M	1
11	8	M	1
13	1	M	1
14	1	M	1
15	10	F	1
17	16	F	1
18	13	M	1
19	11	F	1
25	6	F	1
28	2	M	0
29	3	F	0
30	1	F	1
31		F	1
38	7	F	
39	14	M	1
40	4	F	1
41	2	M	1
42	2	F	1
43	13	F	1
46	16	M	1
47	1	F	1
48	5	F	1
51	7	M	
57	4	F	1
58	14	F	0
59	1	M	1
60	15	F	1
62	4	M	0
63	8	M	0
64	8	M	0
65	9	M	1
70	4	M	1
71	7	F	1
72	1	F	1
74	9	M	1

Age is closest year from given specific age. M is for males and F is for females. 1|mixed breed and 0|pure breed. Blank spaces are unknown information. Cats 2, 3, 4, 18, 19, 28, 29, 70, 71, 72 were not included in prey retrieval analysis because which cat caught the prey item could not be confirmed.

Newspaper Article

Tracking cats to protect wildlife

■ By Bridget Rutherford

A CANTERBURY University student wants to track where house cats venture to in a bid to better protect Travis Wetland Nature Heritage Park – and she needs your feline's help.

Olivia Silvester, a masters student who lives near the wetland, is doing a six-month study on the adventures of cats living within a one block radius of the important native habitat.

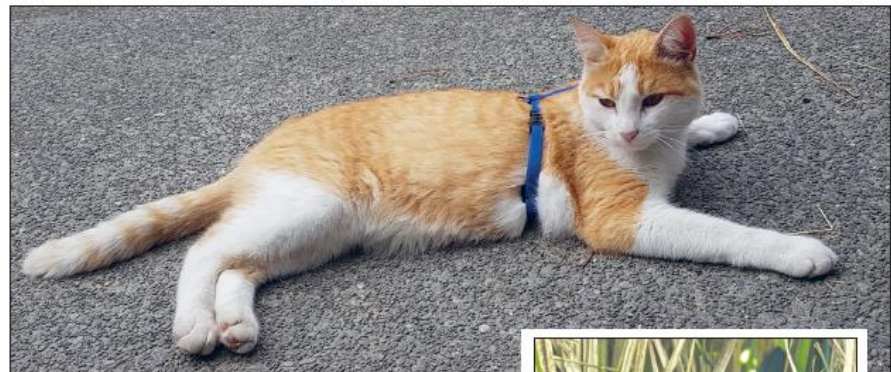
The study would involve attaching GPS trackers to cats residing in the area with harnesses, so where they venture to could be tracked.

The Burwood freshwater wetland has 55 species living there, including 35 natives.

The native short-finned eel, an indigenous skink and about half of Christchurch's pukeko population live there, as well as a diverse variety of insects, birds and invertebrates.

It has a moat to stop cats and other pests from entering, but some still find their way in.

Miss Silvester said she needed about 30 cats to take part in the GPS research, and wanted owners to get in touch if they were interested in their cat being involved.



The GPS trackers would need to be worn 24/7, she said.

"If the cat is uncomfortable the harness can be taken off and the study stopped for that cat."

The study would look at where the cats go, how far they travelled and what they brought home with them, she said.

"The wetlands have a large biodiversity of wildlife from insects to skinks and birds," she said.

"Alongside the harness study, there will be a prey retrieval study looking at what your cat brings home. It will inform us of the main prey items of local cats and we can adjust conservation efforts accordingly."

STUDY: A new initiative will put GPS trackers on cats living near the Travis Wetland Nature Heritage Park in a bid to better protect wildlife there, such as the spotless crane.



About 100 cats were needed for the prey retrieval study.

The owner would be required to note down the items their cats brought home, and store them in provided zip-lock bags.

Miss Silvester said she would visit once a month, or more, to take the items away.

She said the study would also

measure how effective the existing natural barriers were.

Miss Silvester said she would be leaving information in letterboxes in the area this month to see whether anyone would be interested in having their cat involved in the study.

•If you are interested, email olivia.silvester@pg.canterbury.ac.nz

Pegasus Post, Tuesday, March 6th, 2018

Travis Wetland Cat Survey 2018

Thank you for taking the time to complete this brief survey. All responses are confidential and anonymous. No individual cats or cat owners will be identified in the results.

Breed: _____ Coat colour: _____

Age of cat: _____ years and _____ months Male Female Unsure

Size: Smaller than average Medium Larger than average

Desexed: Yes No Age when desexed: _____

No. of times fed wet food a day: 0 1 2 3 4 5 6 Always available

No. of times fed dry food a day: 0 1 2 3 4 5 6 Always available

No. of times fed table scraps a day: 0 1 2 3 4 5 6

How often does your cat usually bring home prey?

Daily Weekly Fortnightly Monthly More than once a year Less than once a year Never

Lifestyle: Indoor only Free roaming Locked in at night

Other (please specify) _____

Does your cat wear a collar: Yes No Does your cat wear a bell: Yes No

Have you ever seen your cat at Travis Wetland Yes No

If yes, how often? _____

How far from your property have you seen your cat?

Home Neighbours Across the Less than 10 More than 10 Less than More than
Only property road houses away houses away 1km away 1km away



If you have any questions or concerns please contact Olivia Silvester at Biology Department, University of Canterbury Ph (03) 3642522 or email olivia.silvester@pg.canterbury.ac.nz

What does your cat bring home?

Birds						Other	
Banded dotterel	Duncock/Hedge sparrow	Gull (e.g. black-backed)	Marsh crane	Starling	Eel	Mouse	
Blackbird	Fantail	House sparrow	Redpoll	Wader (e.g. pied plover)	Fish (other)	Mustelid	
California quail	Goldfinch	Kereu/NZ wood pigeon	Rock pigeon	Welcome swallow	Frog	Rabbit	
Chaffinch	Greenfinch	Kingfisher	Silvereye/Waxeeye	Yellowhammer	Hare	Rat (Norway, Ship)	
Duck (e.g. mallard, grey)	Grey warbler	Magpie	Song thrush	Other	Insect	Southern grass skink	

	Date (d/m)	Time prey found	Place found	Type of prey	Adult (A) or chick (C)	Collected ✓	Other comments
1					A C		
2					A C		
3					A C		
4					A C		
5					A C		
6					A C		
7					A C		
8					A C		
9					A C		
10					A C		
11					A C		
12					A C		
13					A C		
14					A C		
15					A C		
16					A C		

Cat name: _____ Owners name: _____ ID number: _____

Area: _____ Date collected: _____ Month: _____

Please record all prey items your cat brings home. Please take a photo and collect the prey item in a provided polyethylene zip lock bag. Please note down on a piece of paper the date/time you found the prey and what you think it is and put this information inside the zip lock bag. Store the bagged prey in the freezer until I come and collect it. Alternatively, send the photo to me for identification and if the ID is clear I may be able to tell you to throw that item away. I will collect items and the prey record sheet monthly, or more often if contacted by email (olivia.silvestet@pg.cam.ac.uk).

To help identify burbs, see NZ birds online (nzbirdsonline.org.nz). If your cat brings home a live bird I suggest you release the bird outside immediately (after taking a photo is possible), keep your cat indoors for at least 30 minutes. Place baby birds up high on a roof or tree if you can. Birds often die of stress if caught by a cat, so release them as fast as possible.

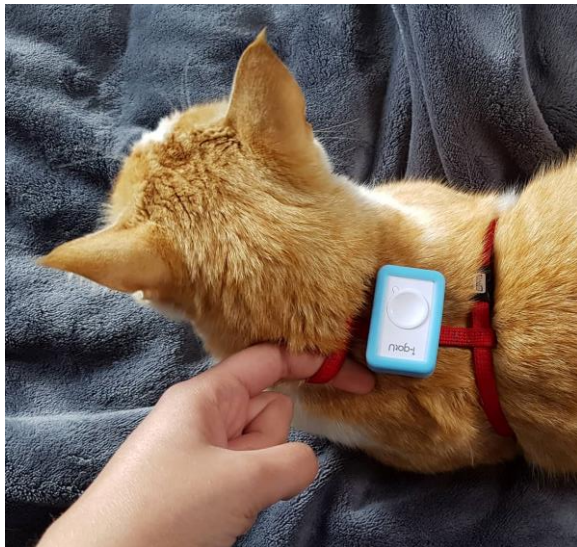


Thank you for your participation!

This GPS tracking method has been used in Wellington, Australia, and the USA. Your participation in my Masters research is greatly appreciated. Hopefully you can discover something new about where your cat adventures to when you're not looking. We can find out how many cats are entering the Travis Wetland in Christchurch.

Fitting the harness

The shorter strap is placed around the neck and the longer strap goes just behind its front legs. The harness should be snug enough that you cannot slide it off past the elbow. The GPS device needs to sit center between the cat's shoulder blades. Your cat can continue to wear its regular collar. Make sure you can fit a finger underneath the straps.



Risks involved

These harnesses do not have the break-away design, but any risks from this can be minimized with correct fitting. In the Cat Tracker project run by Dr Heidi Kikillus in Wellington 2015 and 2016, 209 cats were successfully tracked using these exact methods. Additionally, over 500 cats have been tracked overseas without trouble.

Getting used to the harness



Your cat may seem uncertain of the new harness. Give them time to adjust for a whole day before the tracking begins. I will assist with attaching the harness for the first time and turn the GPS on. Please make sure your cat is behaving normally. The day after is for acclimatisation of the harness. If your cat does not appear to be getting used to the harness at any point, remove it and discontinue the study (email me to let me know please). Every day check your cat for signs of chafing and any discomfort.

Time frame

Day 1	Day 2	Day 3	Day 4	Day 5
GPS unit put on cat Start of recording	Acclimatisation	Day 1 of recording for study analysis	Day 2 of recording	Day 3 of recording
Day 6	Day 7	Day 8	Day 9	
Day 4 of recording	Day 5 of recording	Day 6 of recording	Remove GPS unit in the morning	

I will pick up the GPS on day 9 and I will process the data to generate your cat's map as soon as possible.

The GPS devices are weatherproof and the harnesses can be left on 24/7.

Thank you!



For any inquiries about the study please contact me at olivia.silvester@pg.canterbury.ac.nz



To the homeowner,
I am Olivia Silvester, a Masters student at the
University of Canterbury doing my research on
cats in the Burwood area. I request your help!

Biological Sciences, University of Canterbury
Telephone: Olivia Silvester 0277678376 & Dave Kelly +6433695182
Email: olivia.silvester@pg.canterbury.ac.nz



To the homeowner,
I am Olivia Silvester, a Masters student at the University of Canterbury, and am interested in the conservation and ecology of species. I am surveying the cats around the Travis Wetlands to see what sort of prey they are bringing home and how far their home range is, specifically if they enter the Wetlands or not.

I tried to reach you in person but was unable to.

I am asking for your cooperation in various ways. I would like to know how many cats live at your household. If there is no cat, please let me know as the information allows me to estimate the density of cats in the area. If you have one or more cats could you please let me know. If you would be happy to fill out a one-page survey about them, I will bring you the survey sheet. If you don't want to do the survey, I would appreciate you still email me the number of cats at your household.

If you are happy to help further, I request your participation in the prey retrieval study where you record all the items of prey brought home by your cat for a 6 month period. I would come once a month to pick up any stored prey items and a filled in prey retrieval form or I can confirm the identification over email and then you can throw the prey item out away. For live prey a photo can be sent over email. I will bring you the prey retrieval form after you contact me.

If you are interested in where your cat goes when they're not at home and are happy to take part in the GPS range study, please let me know via email and I can arrange a meeting to see if your cat is fine wearing a harness. The harness would be worn 24/7 for a 7 day period.

See the full information page for more information.

Please email, phone, or text any information and let me know if you are happy to be involved further. Leave your address in the message for identification.

By responding to this survey, you consent to the information you provide to being used for the purposes of the research specified. All information provided will be securely kept by me, Olivia Silvester. No identifying personal information will be shared or distributed in any way. If you wish to participate in the GPS range study, you will be asked to sign an additional consent form acknowledging the unique risks.

Thank you,
Olivia Silvester

Biological Sciences

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The Impact of Cats (*Felis catus*) on Native Skinks (*Oligosoma polychroma*) in Travis Wetlands, New Zealand Information Sheet for Potential Study Participants 2018

My name is Olivia Silvester. I am a Master of Science student at the University of Canterbury interested in the conservation of species. Travis Wetland is the largest fresh water wetland in Christchurch and is a reserve for many species, some which are endangered. To maintain the Travis Wetlands diverse and abundant wildlife, the impact of cats hunting behaviour needs to be studied further. This will be carried out with a cat prey retrieval study and cat range study. A previous study was carried out in 2000 (Morgan et al., 2009 Wildl Res) and this study will compare post-earthquake results with those.

If you choose to take part in this study, your involvement in this project will be to record and collect what your cat(s) bring home over a 6 month period. A survey sheet and polyethylene zip lock bags will be provided to note down prey items and collection. Additionally, if you choose to be involved, for a 6 day period your cats ranging behaviour will be monitored with a GPS device attached to a harness. As a follow-up to this investigation, I will send you a summary of the results via email.

There are very low risks in the performance of the tasks and application of the procedures. For the prey retrieval study, you will need to interact with deceased animals. This interaction is often required to discard of deceased animals anyway, and you will just need to note down the prey item. For the cat range study, it is only to observe the natural behaviour of the cat. The harness is adjustable and the GPS device is carried on the shoulders of the cat.

Participation is voluntary and you have the right to withdraw at any stage without penalty. You may ask for your raw data to be returned to you or destroyed at any point. If you withdraw, I will remove information relating to you.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, no personal information of a sensitive nature will be gathered. Only information on household pets is required. No information will be gathered about the owners. My supervisors and I will be the only ones with access to the data and it will be destroyed in five years. Raw data will be stored on an external hard drive at the University of Canterbury. A summary of the results will be in my thesis. A thesis is a public document and will eventually be available through the UCLibrary. Please indicate on the consent form if you would like to receive a copy of the summary of results.

The project is being carried out as a requirement for a Master of Science degree by Olivia Silvester under the supervision of Dave Kelly (dave.kelly@canterbury.ac.nz) and Elissa Cameron (elissa.cameron@canterbury.ac.nz). They will be pleased to discuss any concerns you may have about participation in the project.

This project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

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Biological Sciences

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**The Impact of Cats (*Felis catus*) on Native Skinks (*Oligosoma polychroma*) in
Travis Wetlands, New Zealand
Consent Form for Potential Study Participants 2018**

- ☐ I have been given a full explanation of this project and have had the opportunity to ask questions.
- ☐ I understand what is required of me if I agree to take part in the research.
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that any information or opinions I provide will be kept confidential to the researcher and supervisors and that any published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.
- ☐ I understand the risks associated with taking part and how they will be managed.
- ☐ I understand that I can contact the researcher (Olivia Silvester, olivia.silvester@pg.canterbury.ac.nz) or supervisors (Dave Kelly, dave.kelly@canterbury.ac.nz or Elissa Cameron, elissa.cameron@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).
- ☐ I would like a summary of the results of the project.
- ☐ By signing below, I agree to participate in this research project.

Name: _____ Signed: _____ Date: _____

Email address (for report of findings, if applicable): _____

If you agree to participate in the study, you are asked to return the consent form to

Olivia Silvester

School of Biological Sciences

University of Canterbury

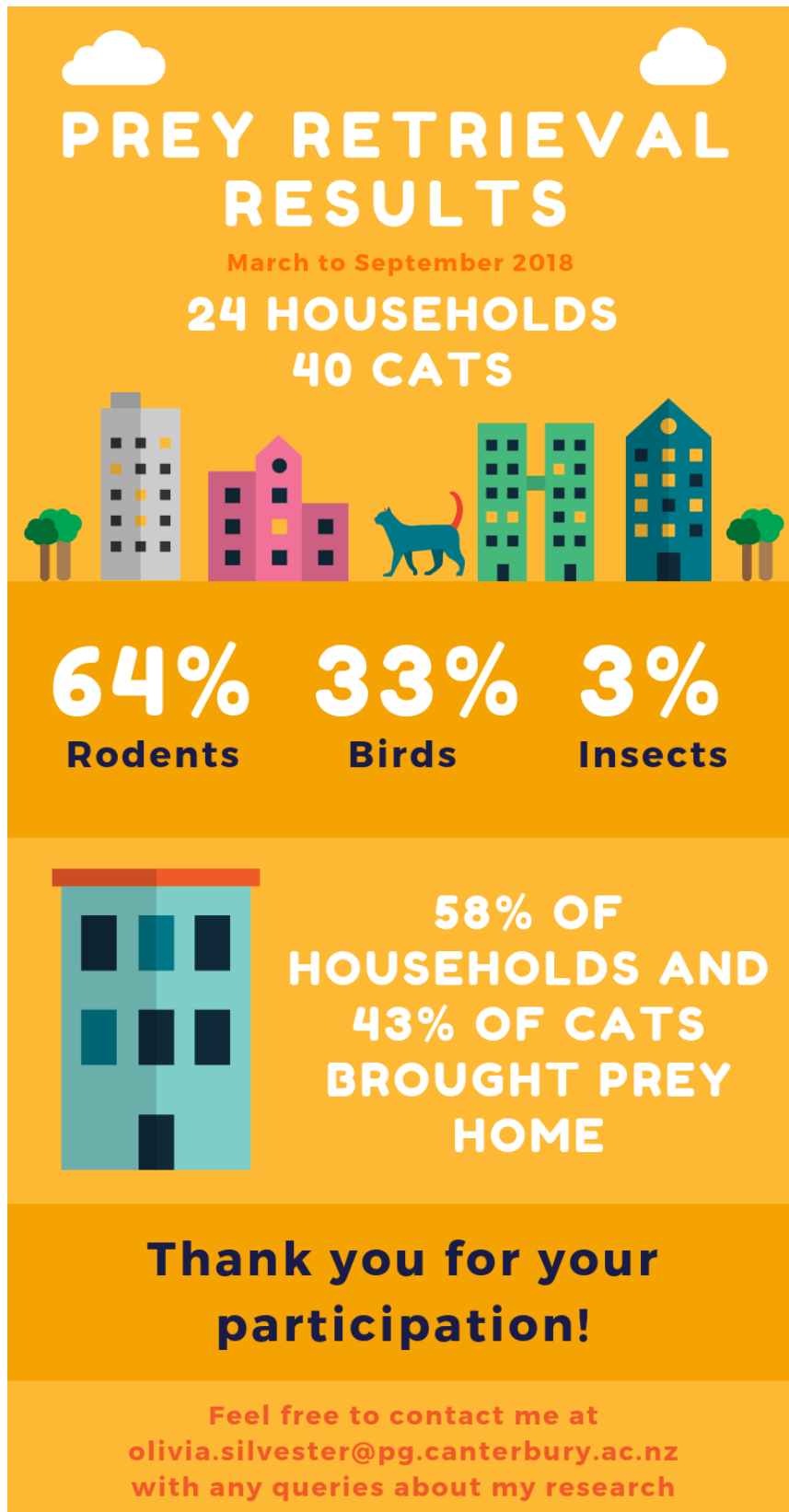
Private Bag 4800

Christchurch 8140

New Zealand

Infographic for End of Prey Retrieval Study

The information is outdated. In the end there were 26 households and 41 cats. There were 62% rodents, 26% exotic birds, and 12% native birds. There were 16/26 (62%) households where the cats brought home prey. Where prey could be assigned to a specific cat 13/31 (42%) brought home prey.



Travis Wetland

Taken by Skyworks (1998 and 2013)



Travis Wetland, 1998



Travis Wetland, 2013